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SOME PROMINENT MEMBERS OF THE FRANKLIN INSTITUTE

6. ELIHU THOMSON, 1853–1937

BY

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Fortunately for the world at large there are scientists who choose to dwell in ivory towers, remote from the market-place, where they can be most productive, but it is equally fortunate there are others who elect to practice the scientific method for the realization of practical ends. Each demands special qualities rarely found in combination. Elihu Thomson was an exception. He was the embodiment of both types of scientist.

Thomson displayed to a remarkable degree the balance of the philosopher, the thoroughness of the scientist, and the constructive power of the inventor. To these he added the finest qualities of the teacher.

Born in Manchester, England, in 1853, he was the second son of Scottish parents. His father was a mill mechanic and engineer with the Scot's flair for the management of machinery. He had been moderately successful until the financial depression of 1857 brought general unemployment to the cotton industry in England and drove him to seek security in the United States. The family arrived in Philadelphia and took up residence in a small thoroughfare near Fifth and Morris Streets. The most distinctive feature of the neighborhood was an expanse of railroad yards, which soon lost its attraction for the little Elihu, who wandered further afield to the bank of the Delaware River. Here he spent the long summer afternoons, motionless in the grass and thickets, entranced by the activities of the insect world.

While still a child he witnessed two astronomical phenomena which awakened an interest in the science that never left him. The first of these was the appearance of Donati's comet in 1858. This made such a

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(Note—The Franklin Institute is not responsible for the statements and opinions advanced by contributors in the JOURNAL.

deep impression on his mind that he expressed a desire to witness a meteor shower of 1867. As this was to be seen to best advantage between three and four o'clock in the morning the boy was persuaded to go to bed while his mother kept watch, making occasional excursions into the street, in order to ascertain when the spectacle was at its height. These youthful experiences stirred his imagination and laid the foundation for an interest in astronomy that culminated in several improvements in the optics practiced by telescope observers.

By the time he was five years old, Elihu had mastered the letters of the alphabet, and could recite them backwards or forwards, as he proudly boasted. This achievement earned for him the privilege of being taught to read by his father. When the precocious boy was sent to school a year later, he made a dramatic debut when his teacher put him to work instructing his fellow-students in their letters. He made such rapid progress through his classes that he passed out of the elementary school two years before he could be admitted to high school. One of the teachers who had taken an interest in the bright student recommended the waiting period should not be spent in study but in building up a strong physique.

This well-meant advice was not strictly followed. Elihu went to work making experiments with whatever crude materials came to hand. By this time the boy's father was working in Cuba, and the boy's upbringing was in the charge of his mother. Aware of his absorption in scientific studies, the mother bought him a copy of *The Magician's Own Book*, a work that described how to conduct experiments with readily obtainable materials. This book had much the same effect as other popular works on science had upon Michael Faraday and Joseph Henry. It confirmed him in the determination to follow a scientific career.

Following the instructions in the book, Elihu made an "electrical machine" from a wine bottle, a crank and spindle, a leather pad, and a silk handkerchief. This was no easy matter for a boy of twelve, who had not only to find his own materials but who had to improvise his tools. He managed to cut a hole in the bottom of the bottle and to fit the spindle into it so that he could rotate the bottle smoothly. Finding he could obtain the desired results with this, he set about making some Leyden jars. In the process of performing this task he revealed at an early age one of the most distinctive characteristics of his maturity, the desire to understand the principles underlying all that he did. In order to make his Leyden jars, he tried to use pink-colored fruit jars, which were readily available. However, he learned this type of glass did not make a good insulator. Instead of abandoning his project, he laid it aside while he made inquiries concerning the composition of the glass which rendered it unsuitable for insulation. Once he was satisfied, he proceeded with more appropriate glass.

The determination to investigate causes accounted for much of his

success as an inventor, for it spared him from the manifold failures that handicap empiricists. The only cause for wonder is that this characteristic should have been in evidence at such an early age.

His father chanced to be home from Cuba at the time this apparatus was completed. Elihu was proud to display it, and his parent was persuaded to submit to a "shock" as the only means of demonstrating he could produce an electric charge with his machine. The effect was not impressive. Disappointed at the indifferent reception of his masterpiece, young Elihu removed the apparatus to his attic workshop, where he cranked up a handsome charge. For a second time his father submitted to the test, but this time he was rewarded with a shock of such violence that he was thrown flat on his back. This convincing proof of his power gained for Elihu not only his father's respect but also the awe-struck fear of the remainder of the family who thereafter kept away from the attic containing such fearsome equipment.

As the years advanced, Professor Thomson showed his attachment to this simple device which represented his introduction to the science in which he was to acquire fame, by preserving it from destruction. It now rests in the museum of his old laboratory at Lynn.

Young Elihu worked his way through the remainder of the book his mother had given him, performing numerous chemical and physical experiments with improvised apparatus. He was not content with making a thing, he had to grasp the why and wherefore of its operation. In this way he gained an excellent training for invention, since he learned how to proceed toward the desired end and was under the compulsion of finding and adapting his materials.

When he reached the age of thirteen he was admitted to the Central High School. For the next four years he trudged the three miles to and from school in all weathers except the worst, often carrying a heavy load of books and papers. Although his favorite subjects were chemistry and physics, Elihu did well in all his subjects. He also displayed an interest in the ephemeral journals prepared and surreptitiously distributed among the students. A more serious literary effort was an article entitled the "Triumph of Science" which appeared in the *Monthly Portfolio*, his first appearance in print.

Having attained the age of sixteen he found employment as a night clerk in the office of the Western Union Telegraph Company. This does not appear to have been any hindrance to his studies, for his class had commenced with 160 students, of whom no more than eighteen graduated as Bachelors of Arts and he was fourth honor man of the class.

Following his graduation he was employed by the Ironmasters Laboratory, 339 Walnut Street, which did testing work for foundries. The work was routine and failed to appeal to the eager youth who had ambitions to engage in original research. He was elated when, after six months of this work, he was unexpectedly invited to fill the position of

"Adjunct to the Department of Chemistry" in the Central High School. As the department had formerly consisted of no one but the professor, young Thomson was, in effect, the assistant professor, but the title was too high sounding for the work he had to perform, which consisted principally of washing bottles and cleaning up after the lectures. In the intervals he found opportunity to convert a basement storage room into a laboratory. Under his ministrations it soon developed into an unusually well equipped laboratory for the period and was probably the first chemical laboratory in an American school.

Thomson was always an observant man, and anything unexpected that caught his attention was at once investigated. Early in 1871, he discovered that when an induction coil was operating nearby, he could draw sparks by holding a penknife blade near to water pipes connected with the ground. This was his first intimation of wireless waves, but he failed to understand the significance of his observation, and he was too fully occupied to make a systematic investigation. However, he did not overlook the phenomenon. He discussed the experience with Edwin J. Houston, professor of natural philosophy at the school, who made it the subject of a communication to The Franklin Institute members.[2] Other papers followed under the name of Professor Houston, but the experiments were made by Thomson and the papers were based upon material furnished by him in discussions with his colleague.

In 1874, Thomson became a member of the Institute. Although he was still only twenty-one years old his ability was recognized by his fellow-members and, in this same year, he was asked to serve as judge of awards in the electrical and "philosophical" exhibits displayed in the Industrial Exhibition of 1874, which marked the Institute's fiftieth anniversary.

Even in these early days of his career, Thomson provided evidence of being an indefatigible worker. Once, when advised to shorten his working hours to save his health, he declined to do so with the comment that ceaseless application to the task in hand was the only way to accomplish anything. He was demonstrating his belief in hard work, for he had supplemented his working day by undertaking night classes. This meant he was frequently at school from eight o'clock in the morning until eleven o'clock at night, during which time he neither ate nor drank. On the few nights he was at liberty he was conducting experiments in his attic workshop which now began to resemble an alchemist's den.

Apart from chemical experiment he was busy making things, a camera, a pipe organ, lenses, etc. He very nearly succeeded in making a telephone six years before Graham Bell did. Unhappily this investigation was broken off by the arrival of the summer vacation, and the insistence of a friend that Thomson accompany him on an expedition in search of

[2] EDWIN J. HOUSTON, "On a New Connection for the Induction Coil," JOUR. FRANKLIN INST., Vol. 91, p. 417 (1871).

geological specimens. On the return from his holiday he became immersed in some other problem and did not resume his work on the telephone. He had been on the verge of a second great discovery.

Thomas Edison had observed a phenomenon which manifested itself in sparks between carbon points held at a short distance from an interrupted current. Not recognizing the phenomenon for what it was, he announced the discovery of an "etheric force." Thomson was familiar with these sparks and did not hesitate to dispute Edison's conclusion. He had made a number of experiments in which he had observed the phenomenon under different conditions. On reading the article in which Edison announced his discovery, he and Houston repeated an experiment, using a Ruhmkorf induction coil with a two-inch spark gap. For a receiver they constructed a black box, open at one side, with two graphite pencil points adjusted to within a fraction of an inch, one pencil point being connected to a large brass ball outside the box. The first test of producing sparks having proved successful, Thomson carried the black box from floor to floor, repeating the experiment until he had reached the observatory on the topmost floor of the school. Here he was still able to draw sparks from the ball.

The outcome of these experiments was sufficient to convince Thomson that the sparks were the result of the transmission of electrical impulses through the air without the aid of wires. This significant series of experiments demonstrated the existence of electromagnetic waves proved mathematically by Clerk Maxwell a decade earlier, and they preceded the experiments of Hertz which led eventually to the development of practical wireless communication.

An account of the investigation was communicated to The Franklin Institute.[3] Normally, Thomson would have continued these experiments until he had thoroughly grasped their meaning, but he had interrupted his routine work only to demonstrate the fallacy of Edison's claim to have discovered a new force. It chanced to be an exceptionally busy time even according to his standards. The family had now moved to Fitzwater Street where he found a more commodious attic from which miscellaneous inventions and improvements flowed in a continuous stream. He was deeply involved in the construction of an electric dynamo and a centrifugal separator. His teaching program was heavy. He had been appointed Professor of Chemistry when his old tutor had retired and he was lecturing at the Institute on electricity to crowded audiences. It was in one of these latter lectures that he perceived through the medium of an embarrassing accident the possibility of achieving arc welding. This incident did not escape his attention or memory. At a later date, when he had an opportunity to make a more thorough examination of the conditions that had brought about the accidental bringing together of two exposed wires, and a current of

[3] EDWIN J. HOUSTON, "Phenomena of Induction," *Ibid.*, Vol. 101, p. 59 (1876).

superior strength was available, he developed the arc welding process on a commercial scale.

During the course of these lectures, Thomson increased his personal acquaintances among the members of the Institute. When he could spare the time he dropped into the workshop in the old building on Seventh Street, where he was able to perform experiments with more advanced apparatus than he could find at the Central High School. Out of the associations he formed grew his enduring attachment to the Institute, where he had a constant group of devoted friends.

He was concentrating now on the dynamo. One of Gramme's famous dynamos had been displayed at the Centennial Exposition and it had fascinated him. After examining it with some care, Thomson was convinced this dynamo could be improved. The constructive activity of his mind was instantly applied to the problem of increasing the dynamo's efficiency. An analysis of the principles involved had enabled him to perceive the direction the improvements should take. Once his way was clear, he began to construct a dynamo of his own design.

While occupied in completing this device he and Professor Houston where appointed judges to advise The Franklin Institute on the purchase of a dynamo. Manufacturers were invited to submit models which were to be judged in competitive tests. Thomson would have liked to submit his own dynamo to the tests but was prevented by his selection as a judge of their merits.

The tests of dynamos broke new ground. Nothing of the kind had been attempted anywhere, and no meters for measuring voltage, current, or resistance had yet been devised. As was usual in any combination with his colleague, the task of designing appropriate measuring devices fell upon Thomson. With these, the most rigorous tests were applied and the report of the judges was a classic of its kind that proved valuable to those who were contemplating the purchase of a dynamo.

The interest in the newly developed electrical industry caused Thomson to visit Paris in 1878, where he hoped to see new machinery in the great Exposition being held in that city. He was greatly disappointed by the exhibits but was impressed by the arc lighting of the Place de l'Opera and the Gare St. Lazare. The over-all impression he gained from this journey was that the electric light was the light of the future, but that the power production was in great need of improvement before this form of lighting could be expected to meet with general approval. However, he was so convinced it had an extensive future that he resolved upon making the provision of the necessary improvements his career.

His time on this journey was not devoted exclusively to technical matters, much of it was consumed by the pleasurable experiences of visiting the chief places of interest in France, Switzerland, Germany, and

England. Best of all he enjoyed meeting the people of these countries. He was charmed by the Parisians. The excursion proved to be so enjoyable that it probably laid the foundation for that love of travel which marked his later years.

On his return home he confided his intention of devoting himself to the promotion of the electrical industry to his colleague Houston, who expressed approval and wished to become a partner in his activities. A partnership was formed in which each man was to draw an equal share in the profits, an arrangement that was much to Houston's advantage since his contributions were of a minor nature.

Thomson lost no time in setting to work. Having a thorough grasp of the conditions, his penetrating mind pierced directly to the most important requirement, the transformer. In October, 1879, he filed his first patent, and before the year had ended he had completed a dynamo, for which he wound the coils in his own workshop. He had realized that slavish adherence to the old induction-coil was a mistake. Instead of using an iron core, he completed the magnetic circuit as well as the electric circuit by surrounding the wire with iron, thereby achieving what he called the "shell" type of transformer.

Ideas came tumbling from his fertile mind, but his association with Houston was to interefere with the advance of the most significant development he had produced up to this time. Thomson felt that his partner was not sharing the burden of producing new ideas or even of making constructive suggestions upon Thomson's designs, all of which were being protected under their joint names. He decided to await an opportunity when he could patent an idea under his sole name. He was engaged at the time upon experiments with the transformer in parallel across the circuit instead of in series. He did not take Houston into his confidence in this work and, when it was accomplished to his satisfaction, he neither published nor patented the idea. This was a fatal mistake. He had anticipated Edison by a year in conceiving the means by which the electric current could be divided. He delayed filing his claim for a patent until 1885. His claim was contested by the examiners and a long legal wrangle was provoked. Eventually his right was conceded in 1902. Meanwhile, manufacturers had generally adopted the idea, and by recognition of his patent rights, a fortune in royalties was due to Thomson. When the case was decided in the courts, the validity of the patent was upheld, but the claim to accrued royalties was disallowed.

To return to Thomson's earliest activities to build an alternating current dynamo, we find that in 1878, he displayed his dynamo and transformer in the hall of The Franklin Institute, using a crude arc lamp of his own design. These demonstrations secured for him friends who expressed their readiness to assist him in the commercial exploitaon of his dynamo. He accepted an offer to build a dynamo suitable for
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commercial application. He had to work under conditions that would have discouraged any man not possessed of a resolute character. His workshop lacked the essential equipment. But he overcame all the obstacles and completed the dynamo. To test it under severe practical working conditions he installed it to light a bakery, where the temperature was almost unbearable. The tests were a complete success, exceeding all expectations. Under these trying conditions of high temperatures he experimented with regulating devices that would enable him to vary the dynamo voltage according to the load it had to carry. In the outcome he was able to provide his dynamo with a regulator that gave him an advantage over competitors.

Thomson was now ready to enter the commercial field. The market did not present an alluring prospect.

Galvanized into activity by Edison's invention of the incandescent lamp, the electrical scene of 1879–1880 resembled a disturbed anthill. Inventors were besieging machine shops with dynamos of revolutionary designs. The cities swarmed with salesmen trying to persuade the authorities and larger individual merchants and industrialists to install some lighting system or other. Two outstanding figures pursued their individual paths, which were not parallel, undismayed by the clamor of their competitors. Edison was much better known, but Thomson's reputation had grown until his work was being appreciated by men who knew little about the electrical science but who did know something about the manner of making a reliable lighting system become a profitable investment. A group of such men persuaded Thomson to foresake the teaching profession in order to exploit his patents through The American Electric Company, promoted exclusively for that purpose.

The transfers of his talents and patents to this company was a gamble. As events were to prove, he could very well have lost control of the patents issued to him, had he not brought to light a very shrewd business sense that protected him. He demanded the inclusion in the contract of a clause which ensured the return of the patents if the directors failed to perform their duties with reasonable diligence. This proved to be a wise course, for he had to invoke the provisions of this saving clause.

The faculty of the Central High School parted from their colleague with many expressions of regret, for he was very popular, but Thomson had the satisfaction of learning that his post would be filled by his closest friend.

Leaving Philadelphia was like beginning life afresh, for it meant separation from family and friends to reside in a town where he had no acquaintances. The only link with his old life was an eighteen year old student who accompanied him. This was E. Wilbur Rice, who was to become a top ranking celebrity in the electrical industry. He also clung to his old title of Professsor. Long after he had been showered with

honors he preferred to be known by that title, ignoring that of Doctor he had gained many times over.

On arriving at the company's plant in New Britain to begin the production of dynamos, Thomson was disappointed, but by no means dismayed, to find nothing in readiness. The plant comprised a small steam engine in an otherwise empty building. With characteristic energy he set to work to construct an entire organization. Progress was dishearteningly slow. The machinery was inadequate, the materials supplied were defective, and he could find no trained workmen. Thomson thrust ahead with grim determination, overcoming obstacles as they arose, remedying faults, training willing workers, and generally getting things moving. He had the energy of a half-dozen ordinary men.

He was fully conscious of the competitive nature of the market into which he had plunged, recognizing that no firm could stand still while others were striving to gain a lead. Improvements to the dynamo and other equipment had to be devised to keep the company ahead of competitors. Since all the improvements must come from his brain, he worked with furious energy.

To furnish the firm with the means of survival he developed ideas that gave the firm advantages that none other could claim. He produced the air-blast mechanism to prevent sparking, a lightning arrestor, and a magnetic switch. He was so fruitful with ideas he was filing claims for patents at the rate of one a month. He was his own draftsman, model-maker, and patent attorney. With such an efficient mind controlling output, the enterprise would have been profitable had there been any corresponding energy in the sales and promotion departments. But here there was stagnation.

Thomson suspected the existence of a deliberate maneuver to force him out of the company and thereby to cause him to lose control over his patents. The legal wisdom he had displayed in drafting his contract saved him from this embarrassment. The saving clause he had inserted into that document rescued him when the directors of the company sold their holdings, leaving him free to associate himself with a group of business men in Lynn who had both the will and the means to give his inventions the promotion they merited. This resulted in the formation of the Thomson-Houston Electric Company which was to acquire world-wide recognition.

The negotiations involved in the transfer of ownership gave Thomson an unaccustomed period of unemployment, which he employed in conducting a series of lectures on electricity to a local group, similar to those he had given to members of the Institute. The leisure also provided opportunity to cultivate social relations, and he became engaged to Miss Mary Louise Peck, of New Britain.

His new business associates were men of a different caliber from the old

ones who had formed his first company, and they displayed an eagerness to progress with the business. In the spring of 1883, Thomson paid a hurried visit to Cincinnati, where an industrial exhibition was to be held that would include a contest for electric lighting systems. He was anxious to have his improved dynamo and its auxiliaries tested in competition with others before a qualified and unprejudiced jury. The judge in this case was Professor T. C. Mendenhall, of Ohio State University, who fulfilled these requirements. After submitting all the material entered to a rigorous examination, a prize was awarded to Edison for his incandescent electric lighting, and one to Thomson for his electric arc lighting system. With this recognition the Thomson-Houston Company was enabled to gain admission to a wider market, and the business began to prosper.

Thomson now realized that the incandescent light would replace the arc light as an illuminant, especially for indoor use, and he determined that his company should adopt it. To this end, he acquired the rights to the Sawyer-Mann lamp and immediately submitted it to a thorough investigation so that it might be brought to the level of the Edison lamp. In the end, the lamp became essentially his own idea. One of the improvements he introduced was the "flashing" process, by which a small quantity of gasoline was admitted to the bulb and this, in burning, contributed to the carbon of the filament, giving the delicate thread a greater strength and longer life.

The Franklin Institute's Electrical Exhibition, the first of its kind ever held, in 1884, attracted scientists and engineers from all parts of the world. Thomson brought his new bride to Philadelphia to see this exhibition. The event was regarded as of such importance that all manufacturers of electrical machinery and apparatus exerted themselves to show their products to the best advantage. Thomson was naturally desirous of learning what competition his company would have to meet, but this gathering of influential visitors had another significance for him.

Although most of the distinguished scientists who visited this exhibition were of an older generation, they welcomed Thomson as their peer. He sat in the councils when they discussed the question of international standards for electrical units, where his views were prized, for it was recognized he was both scientist and philosopher as well as inventor.

Back at work at Lynn after this pleasant interlude, he entered upon the most productive period of his career. During the next five years he produced the electric welding process, the alternating current distribution system, a trolley car, and the electric meter. These were all important developments, for new industries could be erected on each. It is interesting to observe that of all his patents issued thus far, he retained only one as his personal property. This was the patent on the welding process. The origin of this dated back to the days when he was lectur-

ing before the audiences furnished by the Institute, and he had accidentally fused two wires. He had abstained from working out a commercial application of the principle because of the absence of an economical heavy current supply, but the intensive work he had devoted to the alternating current convinced him that the transformer was a versatile affair that could be adapted to electric welding.

The investigation into a suitable transformer for arc welding led to effective developments in the motor which resulted in the production of Thomson's well known induction motor. The odd little repulsion apparatus he constructed for demonstrating the principle behind this, delighted audiences of engineers in New York, London, and Paris. When Professor Fleming borrowed it for a lecture at the Royal Institution, it was not returned to the owner. The Institution begged permission to retain it permanently and, when this was granted, it was displayed alongside Faraday's original dynamo and induction coil.

The routine of intensive experimental investigation was interrupted in 1889 for the purpose of making another extended visit to Europe. He retraced much of his first journey but under different conditions. He was no longer the unknown science teacher, as was demonstrated when the venerable Xenobe Gramme emerged from his retirement to meet the American visitor who had done so much to advance the dynamo. This was but one of the many tributes paid him by European scientists and engineers, although it was one he greatly appreciated. As on his former visit, Thomson derived great joy out of wandering about the streets of Paris, a pastime of which he never wearied, and he missed no chance of exercising his knowledge of the French language, which was so singular that it bewildered everyone but himself.

This vacation was a pleasant interlude in the incessant litigation in which he had found himself engaged, either in defense of his own patents, or in meeting the attacks of other inventors who claimed he was infringing upon their rights.

He was now an acknowledged leader in the engineering field. Although he was resolved upon continuing his research, he desired to be relieved from much of the administrative work of the company, and he wanted to enjoy a greater amount of comfort than he had permitted himself during an arduous life. Besides, with a family of four young sons, a more spacious home was required. To meet family needs and to secure some seclusion he built a handsome home on an estate he had acquired in Swampscott, Mass. It was his hope to find repose here, and to work when the inclination moved him (which was nearly always) without interruption of his research and experiments. Research was his chosen field, and he declined to forsake it.

Not that he was free from tempting offers. When the General Electric Company was formed by the consolidation of the Thomson-Houston and the Edison companies, he was offered a directorship, but

he declined this on the grounds he was not an administrator. He advanced the same argument when, in 1897, he was offered the post of president of the Massachusetts Institute of Technology, although he did fill the post for a short time until a suitable president was found. He clung to his desire to be free from development work in order to devote himself to research. As Rice had moved into a responsible post with the General Electric Company, Thomson chose as his assistant a young Swiss called Herman Lempe, who became as ardent a disciple as Rice had been. Rice was to move upward and onward in the electrical world but if his association with his beloved Professor was loosened, his devotion never wavered. His deep attachement to the Professor was characteristic of the feeling which Thomson inspired in all his associates.

The year 1893 was marked by one of those financial depressions that recur to remind man that he has not conquered economics. While the executives of the newly formed General Electric Company wrestled with the problems that beset management at such dismal times, Thomson remained steadfastly at work in his laboratory, with a much reduced staff. Times such as these are not auspicious for launching new processes, but he had the faith and judgment to persevere with an eye to the future. He worked with Lempe on several new projects, notably the development of an internal combustion engine to consume kerosene, a motor driven refrigerator, and an electric furnace. The first of these was found to operate mechanically with satisfactory results, but the exhaust fumes made it tolerable only when a gale of wind dispersed them. The refrigerating machine was a success, too, but it was premature as too few homes were electrically wired at that time. They fared better with the electric furnace.

When Roentgen announced the discovery of X-rays in 1895, scientists all over the world were eager to investigate their nature and effects. Thomson was no exception, being especially interested in discovering the nature of this form of radiation In the course of the next five years he published twenty-eight papers on the subject in technical journals, and his contributions were recognized to be of such high value that many of these articles were reprinted in foreign countries. The most important discovery he made related to the harmful effect of the radiation and the need to protect the operator. In pursuit of this study he made a test upon two of his own fingers which he exposed to the rays. Providentially, he did not suffer from the cancerous growths which proved so deadly in other cases of exposure, but for the remainder of his life those fingers were scarred, stiff, and annoying.

In 1900 Marconi was successful in transmitting a radio signal across the width of the Atlantic, demonstrating the wide possibilities of the application of that principle that Thomson had observed while at the Central High School. His attitude toward the young Italian inventor brought into sharp focus the generous nature of the older man. Mar-

coni's achievement followed so closely upon the exposure of Dr. Cooke's claim to have discovered the North Pole that it could not fail to arouse suspicion another hoax might be perpetrated, this time with radio waves. Those who should have acclaimed the performance maintained a discreet silence until Thomson was asked to express an opinion. He came to Marconi's support with such warm praise that the timid ones were reconciled to acceptance. His reputation as an authority in the field was sufficient to carry conviction whenever he pronounced judgment.

With new fields of interest opening around him, Thomson never lost touch with his immediate interests. At this period he was as active as a juggler who keeps in the air a top-hat, an umbrella, and three billiard balls. He added steadily to the number and variety of his patents.

There are numerous stories told of the innocent mischief he enjoyed and which underlay the gravity of his public conduct. A very good example relates to his awakened interest in liquid air. On the day he secured his first supply, he conducted a party of friends to a favorite restaurant where he dipped a pat of butter, a steak, and a piece of bread into the freezing liquid to the consternation of the waiter. This bewildered individual rushed off to the proprietor with the complaint the restaurant had been invaded by a troop of magicians. Perhaps he was right. Thomson was daily performing magic with electricity. He had attained a position of prominence that brought all the scientists and inventors of repute to the door of his laboratory—Edison, Steinmetz, Kelvin, Sylvanus Thompson, Westinghouse, and a host of lesser lights. They came to exchange ideas and stayed to succumb to the genial charm of their host. The outer world also knocked on his door but found no welcome. The frequent demands made upon him to accept some office or other, or to lend his name to promote some object, were generally declined in a modest reply. In order not to destroy the effectiveness of his scientific work he had to economize with his time, and to do this he only accepted engagements that were closely allied to his intimate friends and work.

Although he is best known for his electrical work, his contributions to other sciences should not be overlooked. It is not generally known he had disclosed the method of producing a perfectly smooth spherical concave surface by rubbing together two similar glass disks with an abrasive paste between them. This is the method used for grinding telescope lenses and mirrors. This disclosure was made in an article in the JOURNAL OF THE FRANKLIN INSTITUTE.[4] The method is believed to have been originated about one hundred years earlier by an Englishman named Short, who never published any account of the process, and it was the young Thomson's good fortune to rediscover it.

Although his many other pressing occupations left him little time to

[4] ELIHU THOMSON, "A New Method of Grinding Glass Specula," *Ibid.*, Vol. 106, p. 117 (1878).

spare for practical astronomy, the interest he had conceived for it in childhood never left him. He combined this with a study of certain phases of geomagnetism. He was one of the pioneers in the belief that the aurora borealis was associated with sunspot activity, and he stoutly maintained this belief in the face of opposition.

He began to study astronomy more closely after 1900, in which year he built himself a telescope. He made a 10-inch lens on grinding and polishing machines of his own design, and, while he had the heavy casting made outside, all the finishing and construction was performed in his own workshop over the carriage-house of his home. This instrument was comparable with the best professional standards. Thus equipped, he made astronomy his principal hobby.

From early days, Thomson had a distrust of doctors, a feeling which did not diminish in strength as he grew older. It was not that he did not believe in the profession, but only that he conceived original ways of treating ailments that were, to him, highly successful but which did not meet with professional approval. Some of his methods, it must be admitted, could not be approved except when practiced by a scientist, and then only on himself. He had been his own guinea pig from youth, and as he grew in years his methods became more drastic. Finding himself unable to sleep one night from toothache he visited the laboratory where he used a hand-drill to bore a hole in a filling into which he poured raw carbolic acid. He claimed that it stopped the ache. It should be mentioned that he reserved these violent medical ministrations for his own use. Whenever a member of his family was sick he showed himself to be a tender and devoted nurse, although he could not refrain from prescribing remedies of a highly original nature which the medical authorities permitted, it must be confessed, because they could do the sufferer no harm.

Devotion to his family was not reserved for times of illness. An affectionate boyish spirit fairly bubbled over in his relations with his sons, sharing their interests and encouraging their talents. He was not above taking part in their pranks, some of which he gleefully originated. A humble and gentle nature endeared him to members of his family and to a circle of relatives, friends, and co-workers, all of whom responded with an affection that would have resulted in overindulgence had he not resisted their attempts. He insisted in pursuing a rugged individualism that would not tolerate coddling, but found expression in vigorous activity about the house and in his workshop. He abhorred social functions, and took a mischievous delight in practicing an unconventionality that shocked those innocent people who did not understand him.

The workshop was still his greatest attraction, although he was not to be found there at nights as much as formerly. After dinner he was inclined to take his seat at the organ, the same old organ he had built in

his attic when a boy. He had puttered and tinkered with it, had added many improvements he had especially designed for it, so that by this time it had become an efficient instrument. Thomson was by no means an accomplished musician. His ability was restricted to playing a few simple airs, but he extended his repertoire by acquiring an automatic player device and an extensive library of rolls from which he could produce his favorite classics.

All four floors of the workshop had assumed the appearance of a demented junk-dealer's sanctum after years of collecting. Thomson had been engaged upon so many projects, physical, chemical, engineering, and hobbies that it was inevitable he should have assembled an odd collection of machine tools, belts, pulleys, prisms, lenses, bottles, and so on, not omitting stockpiles of glass, copper, and brass, a complete foundry and a blacksmith's shop. It was a superb disarray of everything needed for what he wanted done or contemplated doing. Yet, he could enter this jungle and unerringly place his hand on any tool or piece of material he needed at the moment.

The product of Thomson's inventive genius was impressive. Between 1876, the date of his first patent, and 1935, when the last was issued, he took out 692 patents. The output varied; in some periods he averaged one a week, but the average for his adult life was one every month. Among them were some covering major contributions in the field of electrical engineering, such as the three coil dynamo, electric welding, the alternating current distribution, the uniflow steam engine, the cream separator, the electric meter, several types of transformer, and fundamental improvements in X-ray tubes and high frequency radio apparatus.

A great deal of his work met with no recognition at the time, or was attributed to others, but he met with many rewards from those in a position to appreciate what he had accomplished. Universities showered degrees upon him; the scientific and technical societies offered their highest awards, among them the Franklin Medal and the Kelvin Medal. But as eminence increased, the years were passing. Time brought both rewards and sorrows. If Thomson lived to know he was increasing in the esteem of his fellow workers, he knew also the sadness that comes from the deprivation of those he loved. He had lost his wife and a son; old friends had gone whose loss seemed irreparable. As for himself he was slowing down; he who had preached and practiced ceaseless energy was beginning to grow tired. Friends began to think of him as a wistful old man as he neared his 70th anniversary.

Then came a bright revival. A mutual interest in photography caused him to meet Miss Clarissa Hovey, and it was not long before they discovered they had other interests in common. They were married in 1923, and a new joy entered Thomson's life.

The year of their marriage was memorable, because the Thomsons

set out to see more of the world—the West Indies, London, Paris as a prelude to more extensive tours in Africa and South America. But during this year of 1923 Thomson was thoroughly enjoying himself. He was working, too, for he could never divorce himself from his various interests, as a flow of articles communicated to technical journals was to prove. Just in time to be received as a Christmas gift was the notification the Royal Society had awarded him the Kelvin Medal, which he was invited to receive at the Kelvin Centennial celebrations.

In 1925 he came back to Philadelphia to accept the Franklin Medal "in recognition of his pioneer work in the field of electricity and electrical engineering, and his numerous inventions in those fields." He proved, however, that electricity was not the only field in which he labored, for his acceptance speech dealt with the subject of fused quartz.

This was a premonition of things to come. Thomson was about to embark upon the formidable task of making the 200-inch mirror for the Mt. Palomar observatory telescope. One can only marvel that he, who had passed his 75th birthday, should saddle himself with a task of such complexity. For he projected making this vast mirror from quartz, and fused quartz at its best is a stubborn material. To produce and process it required the development and application of new techniques. Some of the main obstacles were overcome but complete success could not be achieved within the bounds of reasonable expense. Reluctantly, the project had to be abandoned. Unluckily, the newspapers had drawn a great deal of attention to the work, attributing ideas to Thomson he had never held. The attribution of these ideas to him aroused his indignation. He got really angry over this unreasonable treatment, but he took care to conceal his feelings from the public.

In the twilight of his lifetime he withdrew from the great laboratory which he had originated, but nothing could keep him from his private workshop. There was no creaking of the mental joints. He was still keenly interested in the work the laboratory was performing, even if he did not have a hand in it.

When he reached his 80th birthday, his friends arranged a scientific conference in his honor, in which scientists and engineers might have the opportunity to pay tribute to his greatness. It was a tribute from an industry he had seen grow from infancy to mammoth size. Dr. Karl T. Compton paid him a compliment that expressed the opinion of the whole gathering when he said: "It is fitting to say he has contributed more than any man now living to the creation of what we call 'The Age of Electricity.'" Owen D. Young spoke of the material results of Thomson's labors when he said the plants of the General Electric Company had a valuation of $209,000,000 and the assets of the company amounted to $500,000,000. Then speaking of the company's balance sheet, he declared: "There is not an item on that sheet which could have existed at all, or if it did exist, would have been worth putting on the

asset side of any balance sheet had it not been for the work of Professor Thomson and Edwin Wilbur Rice. There is not a separate identifiable thing that stands there as their monument—it is the balance sheet itself."

The time for achievement had passed, the great pageant of his life's work could be viewed in retrospect, and he had but three more years of life granted to him. They were not years of placid repose. Only a man of extraordinary robust strength could have endured the strain. There were times when it did not seem possible he could survive the crisis, but he would rally and find a cheerful consolation in examining the gadgets that were sent from the factory or laboratory. Death came to him on March 13, 1937, a few days before his 84th birthday.

His life had been simple, his attitude friendly and unselfish, exemplifying the spirit of helpfulness and cooperation. With a true scientist's devotion to the common welfare, he shunned publicity and, therefore, was not well known to the outside world, but he was honored and rewarded by those whose approbation he valued. "What Elihu Thomson did made him distinguished. What he was made him great," might very well serve as his epitaph.

Automatic Respirator.—An ingenious apparatus for coaxing new-born babies to breathe was shown at an exhibition held by Britain's Royal Society late in May.

The most common cause of deaths in new-born infants is shortage of breath, caused by defects in the lungs or by general weakness which prevents normal breathing. These difficulties are often only temporary, and the baby will recover if he can be tided over the emergency by an artificial respirator. Unfortunately machines used for paralyzed adults, delivering a dose of air at regular intervals, will not do for the new-born baby, who often takes a few breaths and then rests for a while before starting again. If a regular rhythm is imposed by a machine, the infant struggles against it and does not take in enough air to keep itself alive.

The new machine is an electronic respirator which is actually controlled by the infant itself. When the baby makes an effort to take in breath, a small pressure change in his face mask operates a sensitive trigger valve and brings an electronic controller into operation. The original impulse supplied by the baby is amplified and used to open a valve connected to an air or oxygen cylinder. In this way the baby receives breath when it wants it.

But the amount of air that it gets is not limited by its own feeble strength. If the child stops breathing for a dangerously long time, the machine takes charge and gives it breath without being asked. But as soon as the child makes another effort itself, the machine responds to it.

The machine, developed by a team of doctors, engineers and physicists, is in regular use for the treatment of respiratory difficulties in premature babies and other new-born infants at the Royal Maternity and Women's Hospital in Glasgow, Scotland.

The apparatus may have application to the treatment of adults, particularly in respiratory paralysis after poliomyelitis.

It is reported that a modified version may be produced commercially.

Lighter, Stronger Sheet Protectors.—Pity the poor salesman with the overstuffed briefcase! A partial solution is offered by a new transparent sheet protector which enables a salesman to carry up to 50 per cent more presentation and reference material in the same amount of space.

Sheet protectors made of transparent film are widely used for protecting albums, displays, reports, presentations, and other papers against dirt and handling. The new protectors, made of "Mylar" polyester film, are thinner, lighter, and stronger than protectors made of other films, according to the manufacturer.

Weight of the new protectors is approximately 50 per cent that of other protectors, since the strength of "Mylar" permits use of film only 0.002 in thick. Reinforcing is unnecessary, since the punch holes will withstand a 60-lb. pull without tearing, according to the manufacturer.

Because of the thin gauge film, a standard 1-in. binder will hold 55 sheet protectors as against 35 to 45 of any other kind, it is claimed, thus providing additional space for crowded storage facilities. The protectors have excellent scratch resistance, clarity, and will last almost indefinitely since the film is not affected by moisture, temperature, or age.

Sheet protectors of "Mylar" polyester film are manufactured by the Joshua Meier Company, Inc., New York, and are available at stationery and department stores throughout the country.

LEVEL VIALS—THEIR MANUFACTURE, USE, AND PECULIARITIES

BY

DOUGLAS L. PARKHURST [1]

This article has been written to describe this interesting device, which is a component of nearly all surveying instruments and many other items of scientific apparatus, to say nothing of various types of mechanics' tools.

It is a most useful and fairly inexpensive element, capable of rendering very versatile and extraordinarily accurate service. The surveying instrument industry is virtually dependent upon it.

As there seems to be a singular dearth of literature on the subject, in fact, appearing to be almost nonexistent, this article has been prepared with the idea of describing some of the salient features of level vials, including some of their pecularities, with the hope that further research may be stimulated which will ultimately find solutions to some of the problems connected with them, such as the matter of bubble creep in the direction of illumination and the formation of "crystals."

The Coast and Geodetic Survey, organized in 1807, has probably had a longer experience with the use of level vials than anyone else in the United States, as precision vials are used in nearly all the Bureau's major instruments, and while the level vial is an item that is deceptively simple in appearance, its manufacture and use present a number of interesting problems, some of which still await satisfactory solution.

The writer believes that level vials have considerable potential use as extremely sensitive indicating devices, not subject to wear or mechanical error, which are capable of readily detecting surface irregularities on the order of half a micron.

Vials may be divided into three general categories, spherical, bent and barrel-shaped. Spherical, also known as circular, vials are spherical in the sense that the upper inside surface over which the bubble travels is spherical, the rest of the vial being circular in cross section. This is one of the simplest of the leveling devices and is frequently used to rough level a precision instrument where a precision vial, of necessarily limited range, is to be used for final leveling.

This type of vial is filled with liquid through a tip in the base to the point where only a small bubble remains, the tip then being sealed off with a torch. The top center is marked with a lightly etched circle, preferably about one and a half times the diameter of the bubble at normal temperature. Vials of this sort are usually mounted in a light metal or

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plastic holder, cemented in place with plaster of paris, and find many uses as universal direction levels.

Bent vials are made from a good grade of cylindrical glass tubing, by heating and bending over a form of the requisite curvature to supply the degree of sensitivity of bubble movement which is desired. Such a vial usually has two transverse lines etched at the highest point of the arc, spaced the bubble length apart, and are filled with a liquid having an appropriate viscosity for the use to which the vial is to be put.

Glycerin or some of the lighter petroleum oils, or alcohol if greater sensitivity is required, are frequently used.

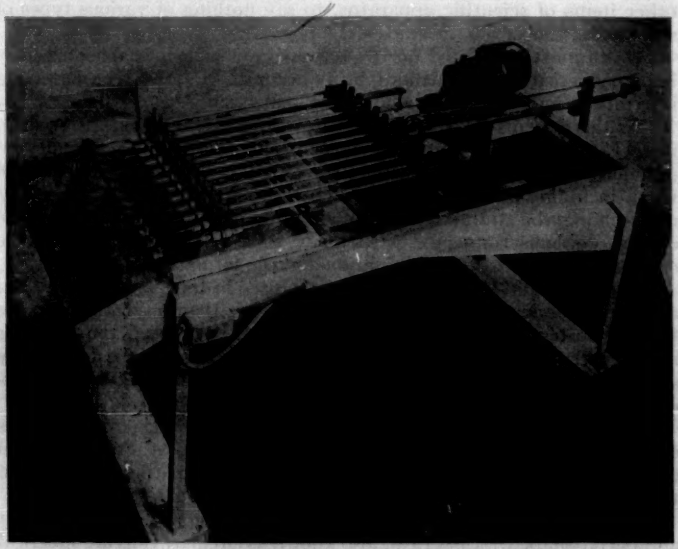

FIG. 1. Level vial grinding machine.

After sealing (see methods of manufacture), vials of this sort are usually mounted in the using instrument or tool, in plaster of paris, the vial being adjusted during this process so that the bubble lies between the lines when the instrument is level.

Bent vials are used in carpenters' and masons' levels, minor surveying instruments, and similar devices.

Precision and semi-precise vials have barrel-shaped interiors, their outer surfaces being cylindrical. Their inner surfaces are ground to a curve of large radius. These are used where higher accuracy and greater

sensitivity are desired, such as in machinists' levels, and surveyors' transits, levels, astronomic instruments, etc.

A good grade of glass tubing is required, and the interior is ground in a special machine, one form of which is shown in Fig. 1.

This is an interesting machine. It is of course essential that the inner surface of the vial be not only smoothly ground but to a uniform curvature of the desired radius. For instance, a vial of one minute accuracy must be ground to a radius of about 22 feet. To do this, a lap in the form of a rod small enough to pass through the vial blank is curved to the required radius and the blank placed over it and the lap fastened in the machine.

A cylindrical gripping device holds the blank, and as the machine is operated the blank vial is passed back and forth along the lap, at all times being rotated in such a manner that the rotative velocity is directly proportional to the linear velocity so that the grinding effect is constant.

The lap is kept wet with water and fine abrasive such as carborundum, to grind the glass quickly to the proper shape and finish. In practice, the machine may grind numerous vials at one time.

The mechanism for rotating the vial blanks is quite ingenious. A geared down electric motor mounted on the frame of the machine has a crank attached to its shalft with a pin which slides in a slot in a bar fastened to the end of the carriage which carries the vial gripping device. As the crank revolves, the carriage is drawn back and forth.

An endless belt passes around two pulleys attached to an extension of the carriage, and this belt is secured at one point to a part of the frame of the machine so that as the motor turns and the carriage moves back and forth, the belt remains partially fixed in position. The relative motion between the belt and the carriage is utilized to cause the pulleys to turn and thus rotate the vital grippers through a gear system so that the vial is passed back and forth along the lap and rotated at the same time in such a manner that the rotative speed is always proportionate to the speed of translation.

Vials are sometimes ground by hand. In this case the same sort of lap is used as in machine grinding, but the vial blank is turned by hand, using a tool usually made of wood, which is shaped like a wide bladed paddle or putty knife. The function of this tool as it is rubbed over the glass tubing is to cause it to rotate, grinding the interior in the same manner as the machine. To grind a precise vial by this means requires a high degree of skill to maintain even speeds and pressures so that a vial with constant radius of curvature will be produced.

Vials suitable for use with instruments of high precision such as theodolites, geodetic levels, astronomic instruments, etc., usually lie in the sensitivity range between one and ten seconds of arc per 2-mm. division (movement of bubble) which is an accepted standard of spacing. Such

vials have exceptionally large radii of curvature, up to 700 ft. and, with so flat a curve, bubble movement is extremely sensitive. Any irregularities of the inner surface such as flat places, rough grinding or formation of crystals are immediately apparent.

Vials of this sort are affected to a rather pronounced degree by temperature changes which alter bubble length, consequently they are usually constructed to have an auxiliary reservoir, or chamber as it is called (see Fig. 2). Filling liquid may be transferred from chamber to main

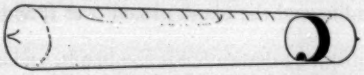

FIG. 2. Chamber in level vial.

body of vial and return through a small opening in the diaphragm which separates the tube into two portions, to keep the bubble length constant. This is done by tipping the vial (or instrument) to allow the liquid to flow. When the instrument is horizontal, the position of the opening is on the underside so that liquid will not transfer accidentally. The chamber should have sufficient capacity to entirely fill the bubble (see Fig. 3).

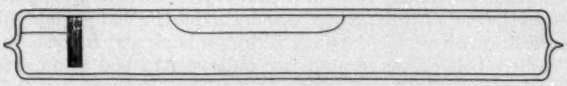

FIG. 3. Liquid in vial body and chamber.

The chamber is usually formed by the insertion of a diaphragm of glass about 3/32 in. thick. It must be carefully ground to the requisite diameter so that it will fit tightly into the tube at the proper position to form a chamber of correct capacity.

The writer has noted an interesting deviation from this design, where the chamber was formed of a thin bubble of glass only slightly smaller than the bore of the vial. The opening for transfer of liquid was formed by utilizing the principle that a plane passing through a sphere intersects it as a circle. In practice, a small flat surface was ground across a rounded corner, cutting through the chamber wall to form a sharp edged circular hole, an ideal form. Liquid transfers easily and quickly where this design is used, whereas in the thick wall diaphragm type, if the opening is too small, transfer may be slow and difficult.

Chambers of this sort are apparently blown with a stem that is fused into the end of the vial during the sealing process, which prevents the chamber from coming loose, which sometimes occurs in the diaphragm type.

FILLING PROCEDURE

After the vial has been ground to proper curvature, one end is heated and fused shut. The other end is heated and drawn down to a very fine tube.

The empty vial is next placed in a rack with this fine opening upward and is submerged in a container of the filling liquid, then placed under a bell jar or similar device which may be evacuated. After evacuation, release of the vacuum allows atmospheric pressure to force liquid into the vial. This process is repeated until the correct amount is introduced.

The fine filling tube is then quickly sealed by fusion in the needle-like flame of a glass blower's torch. The hole in the tube must be so small that there will be no danger of snapback ignition of the filling material.

Filling and closing methods have undergone a certain amount of change as the art has progressed. At one time, one end of the vial was closed with a ground glass stopper, see Fig. 4, and still another type

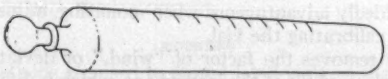

FIG. 4. Stopper-type vial closure.

exists in which each end of the tube was closed with a brass and fiber plug with a spring-shaped metal rod connecting the two plugs. A sealing compound was used to prevent leakage and filling was through a small screw hole in one plug. These represent an evolution in the present fusion method of closing.

FILLING MATERIALS

The liquid to be used will depend upon the degree of sensitivity required. The fairly insensitive vials used in carpenters' levels may be filled with glycerin or a material of similar viscosity. For greater sensitivity, alcohol may be the filling liquid. Precision vials are usually filled with sulphuric ether, iso-pentane or similar liquids. It is essential that the viscosity of the liquid remains nearly constant throughout the expected temperature range which the vial will experience. This is of course particularly true with the more sensitive vial.

It is also necessary that the liquid have low mass to avoid objectionable inertia effects. Some of the silicone liquids satisfy the viscosity requirements, but, in the writer's experience where a silicone liquid is used, the inertia of the bubble results in unsatisfactory performance.

TUBING

The basic raw material of the level vial is the glass tubing from which it is to be formed. Chemically, this glass must be unaffected by the

liquids which it is to contain and it should possess certain mechanical characteristics.

Commercial glass tubing, even of the best grade, is not manufactured to any great degree of exactness as to diameter, circularity or uniformity of wall thickness, as close tolerances are unimportant in the usual uses of this material. For level vial use, however, true cylindricality and concentricity of both outside diameter and bore are highly desirable features as otherwise difficulty is experienced in vial calibration, and vials made of irregularly shaped tubing are difficult to mount in the using instrument, in a manner which assures that the bubble travels along the same radius as that calibrated. Incorrect data are sometimes obtained where such vials are used.

This difficulty may be overcome by the use of "precision bore" glass tubing, a material which is formed over a mandrel in a manner which provides tubing having both interior and exterior surfaces cylindrical and concentric within very close tolerance. The use of this type of material is decidedly advantageous when mounting, adjusting, and particularly when calibrating the vial.

It virtually removes the factor of "wind," or deviation of bubble path from the plane of tilt of the instrument, which is difficult to eliminate when vials are made from conventional stock.

GRADUATING

Precision vials are used to indicate the level position of an instrument, and in addition, to measure small deviations which may occur from the level position.

Where only the level position enters into consideration, which is the case when observations are quickly completed, only two graduation lines are required, spaced the bubble length apart, and these are etched into the glass.

Some types of work, however, such as astronomical observations, cannot be completed quickly and the instrument may take on a perceptible tilt for a variety of reasons, particularly when portable instruments are used and foundation supports are none too rigid. It is not considered advisable to re-level the instrument if it can be avoided, so recourse is made to having the level vial graduated through a sufficient range to cover the entire run of the bubble, the lines being numbered for the observer's convenience. Graduation lines are spaced 2 mm. apart, and the vial is calibrated so that the amount the instrument has tilted may be determined at each observation, and corrections applied.

To facilitate calibration and mounting in the using instrument, it is advisable to apply a single short longitudinal line at the mid point of the vial, this line being useful when testing the vial, which is turned until this line comes into register with a pointer, to insure that the vial always lies in the trier in the same position.

In the description of the grinding process we have seen how carefully the barrel-shaped interior surface must be formed to the correct contour in an arc of long and uniform radius if the vial is to function satisfactorily. As it is virtually impossible to grind the interior to a predetermined radius, precision vials are customarily carefully tested in an instrument known as a "level trier," to determine their "sensitivity," the accepted units being seconds of arc per 2-mm. division of length of vial.

WIND

When installing a precise level vial on an instrument, particular care should be exercised to avoid "wind," or placing the vial askew wherein the bubble, as the instrument is tilted, does not run along the curve of the carefully ground and calibrated radius but on a curve representing the intersection of a plane passing through the vial at a slant with the true axis, in which case the curve is not an arc of a circle but an arc of a variable and unknown radius which may introduce serious errors in the observations made with the instrument.

MOUNTING

Various methods are used to mount level vials on their using instruments and devices. Vials of low sensitivity, such as those on carpenters' and mechanics' levels, and for surveying instruments of lesser accuracy, are customarily set in a bed of plaster of paris in a tubular metal holder. This, of course, is rigid and will not serve for vials of a more sensitive character, where a resilient method of mounting must be used to avoid setting up any strains which may distort the vial and change its radius of curvature.

Accurate vials should be mounted so that no strain will be caused by any relative change in dimensions along the longitudinal axis between the vial and its holder. The vial, however, must be restrained against movement in any other direction, including rotation.

Various methods for accomplishing this purpose are used by different instrument makers, and as long as strains and movement are avoided, the particular method used is perhaps not too important.

One design frequently used is a form of three point support. The vial slips loosely into a tubular metal holder, each end resting on two small points on the lower side of the holder, spaced approximately 120° apart, the vial being held against these points by an opposing flat spring. Endway slippage and rotation are prevented by small plugs of resilient cork which fit loosely over the vial ends and into the holders, the plugs being lightly compressed when assembling. Sometimes helical springs are substituted for this cork.

TESTING

The "level trier" is a testing device for tilting the level vial in precisely known amounts so that comparison may be made between the

observed movement of the bubble and that for which the vial was designed. A variety of designs may be used for such a testing instrument, a sample form of which is shown in the illustration (see Fig. 5).

This is a tee-shaped bar having a micrometer screw at the end of the shank of the tee, the tips of the head resting on spherical shaped bearings so that the length of radius of tilt is maintained throughout the working range.

It is essential that the test instrument at all times be free from strain and that the act of testing shall not cause any motion except in the desired direction. The method of mounting the instrument on its base must satisfy these conditions, including compensating for effect of changes in temperature, and to do this we make use of the point, line and plane types of bearing.

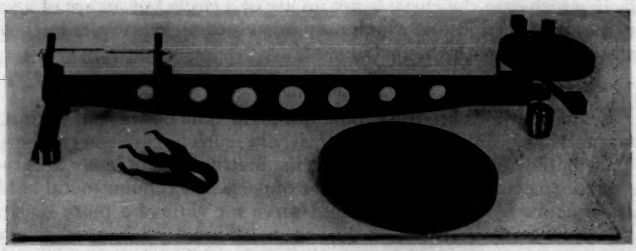

FIG. 5. Vial trier.

One of the spherical tip bearings rests in a cone-shaped cup in the base so that its movement is restrained in the horizontal plane while the other lies in a vee-groove located at 90° to the axis of the trier, permitting expansion and contraction of the head without disturbance of the adjustment of the device.

The end of the micrometer screw is a plane which rests on top of a steel ball embedded in the base so that the trier rests on a three point support and no distorting strains are set up in it due to temperature or other dimensional changes, yet the instrument is restrained to movement only in direction of tilt.

In the trier, shown in the illustration, the tilting arm is of the proper length to permit the use of a conventional mechanic's micrometer head with an enlarged dial reading to 0.0002 in. so that one division equals 2 seconds of arc. In test, the vial is placed in a vee-shaped holder on the arm, the greatest of care being taken that the axis of the vee lies in the vertical plane of tilt so that movement of the vial will lie in this vertical plane and the bubble travel along the true arc of curvature ground in the vial, as otherwise it will fall into a path which is not a true arc of a circle.

Any deviation from such correct positioning of the vial so that it lies slantwise is known as "wind." The same care must be taken in mounting the vial in the using instrument to avoid this condition.

Testing of vials at the Coast and Geodetic Survey is carried on according to the instructions below, the data being recorded on a form. A sample set of observations is exhibited which includes movement of bubble from right to left, and reverse. A similar run is made with the vial reversed on the trier, and its value determined by summation of the four sets of readings.

INSTRUCTIONS FOR DETERMINATION OF LEVEL VALUE

With level vial in position, chambered end right, turn the micrometer until the left end of the bubble is near the left end of the graduations on the vial. Set the micrometer to an even division and read both ends of the bubble, estimating to the nearest tenth of a division. Reset the micrometer to an even division so that the bubble will move to the right approximately one twentieth of the number of marked divisions on the vial to the right of the right end of the bubble. Read and record both ends of the vial. Continue this procedure changing the reading of the micrometer the same amount each time until the right end of the bubble has moved close to the right end of the scale. Then in the same manner, record readings as the bubble is moved from right to left. Strike out the word "left" in "Chambered end right (or) left" in headings of columns.

Reverse the level vial, thus bringing the chambered end to the left, and repeat the determination exactly as outlined above, except that the bubble should be started near the right hand end of scale and be moved first to the left and then to the right. Use additional copies of the form for these readings and strike out the word "right" in "Chambered end right (or) left" in headings of columns.

The amount each end of the bubble moves for each new setting of the micrometer is computed in the columns headed "Difference, L. R." In order to detect irregularities in the vial, level values are computed by dividing the interval between successive micrometer readings by the number of divisions the bubble moves between observations. The level value for each set of observations is derived by summing successive computed values and dividing by the number of computed values.

The final value is determined by summing the level values derived from each set of observations and dividing by the number of sets (see Fig. 6).

CRYSTALLIZATION AND RUN

Two somewhat perplexing troubles are apt to develop in precise vials, especially those filled with ether, and these are the formation of from one to myriad tiny "crystals" on the interior of the tube, and the other is the tendency of the bubble to drift when unevenly lighted, in the

direction of the most intense illumination. The reaons for these phenomena are not definitely known although there are various theories.

With respect to crystallization, it has been noted that crystals may form in a new tube in a short time or it may be years before their occurrence. Also, many may form, so much so that occasionally the inside of the vial may literally be covered with them; at other times there may be only a single crystal, which is perhaps even more objectionable as in all probability it will only be detected when the bubble begins to behave erratically. Small crystals are nearly transparent and hard to see. The "crystals" sometimes have the appearance of tiny but solid particles

DEPARTMENT OF COMMERCE
U.S. Coast and Geodetic Survey

Form No.

DETERMINATION OF LEVEL VALUE

Vial No. 310

Observer John Doe Temperature 87F Instrument No. _____

Set No. 1 and 2 Date Aug. 6, 1956

	Chambered end (right) - (left)						
	Micrometer Reading	Bubble Reading Left End	Bubble Reading Right End	Difference L	Difference R	Mean	Successive Level Values	REMARKS
Set No. 1	72	2.0	20.2				
	69	3.3	21.4	1.3	1.2	1.25	4.800
	64	4.4	22.5	1.1	1.1	1.10	5.455
	63	5.7	23.8	1.3	1.3	1.30	4.615
	60	6.5	24.7	0.8	0.9	0.85	7.500
	57	7.7	25.8	1.2	1.1	1.15	5.217
							27.587
	57	7.6	25.7				
Set No 2	60	6.6	24.7	1.0	1.0	1.00	6.000
	63	5.7	23.9	0.9	0.9	0.90	6.667
	66	4.5	22.6	1.2	1.2	1.20	5.000
	69	3.7	21.8	0.8	0.8	0.80	7.500
	72	2.1	20.2	1.6	1.6	1.60	3.750
							29.917
							Sum
				Level value set No. 1			5.517
				" " " " 2			5.783
				" " " " 3			6.348
				" " " " 4			5.305
				Final Level value			21,953 / 5,391

H-138

FIG. 6. Vial test data.

of substance adhering to the inner surface of the vial. They also at times appear in the form of tiny droplets of some foreign liquid, presumably of greater viscosity than that of the filling material. In either case, the result is the same. The bubble does not run smoothly, hanging on the crystal until the instrument is tilted sufficiently to dislodge it. Obviously an instrument cannot be leveled properly when this condition obtains. Crystals of the droplet type behave in the same manner as the hard type. Some believe crystals are formed by virtue of a chemical action between the liquid and the glass. A contamination theory lends support to the idea that the filling liquid, usually dispensed in soldered metal cans, may dissolve traces of the flux used in soldering, which later coagulates on the surface of the glass. It is also possible that small amounts of water vapor may be absorbed by the liquid during the filling process and later condensed on the interior of the tube. The writer recalls that one manufacturer prefers not to fill vials on days of high humidity, on this assumption. As an elementary precaution, the filling liquid should certainly be passed over a drying agent to remove any trace of moisture.

Fortunately, vials having this trouble may be cleaned and refilled by makers without altering their sensitivity. This work is usually performed at the owner's risk, but a high degree of success usually prevails.

Bubble creep is the tendency of the bubble to move in the direction of highest illumination. By turning the rays of a flashlight onto a sensitive vial which is in the level position, the bubble may readily be caused to move back and forth. An interesting explanation of this odd behavior has been advanced by a member of the Gurley Company's staff, which seems to be borne out by experiment. This theory is that any contamination of the filling liquid impairs its transparency, resulting in surface reflections.

Thus, as the liquid curves upward at the end of the bubble in a concave meniscus, some of the light rays are focused on the wetted surface of the tube inside the bubble, causing unequal evaporation (drying) of the glass, upsetting surface tension of the liquid, the bubble then moving in the proper direction to restore balance.

It is reported that experimentation, using a filling liquid of wood alcohol, which had been carefully distilled into a clean glass container so that no contact with any contaminant had occurred, resulted in a vial free from creep.

The greater the sensitivity the more pronounced is the effect of crystal formation, creep, and wind in the mounting of the vial. Vials of 1- to 2-seconds sensitivity are used in the most precise surveying and astronomic instruments and as the curvature of such a vial is on the order of 700 to 800 ft. in radius, which occasions only a few thousandths of an inch difference between the major diameter at the middle of the

vial and the minor diameter at the ends, it is easy to see how any slight irregularity will destroy the vial's usefulness.

Such vials are so sensitive that earthquake waves, originating thousands of miles away have been detected as bubble movements during vial testing.

SUMMATION

It is the author's belief that level vials have many potential uses because of the extremely small and accurate measurements that may be made with them and their freedom from mechanical wear and error, but improvements must be made in methods of constructing and filling.

A grinding machine, more massive than the one illustrated and which should be mounted on a heavy pier, would be an improvement to insure vibrationless grinding and provide a smoother and more uniform interior surface in the vial. Filling liquids should be used which are known to have no chemical effect on the glass and which have been processed to insure freedom from any contamination. Filling the vials should be conducted under circumstances which eliminate any chance of moisture inclusion.

The instrument industry needs a vial whose bubble runs smoothly and evenly and whose sensitivity may be accurately determined. It must be free from crystal formations so that its calibration and sensitivity will not be impaired, and it should be filled with a liquid which will not be adversely affected by age, temperature changes or the method of illumination. Many additional uses for such a tool can be found.

Acknowledgment

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MECHANICS OF HIGH SPEED PROJECTILE PERFORATION *

BY

MELVIN ZAID [1] AND BURTON PAUL [2]

ABSTRACT

The problem of perforation of thin plates by high speed projectiles is considered from a momentum viewpoint. Equations representing the magnitude and direction of forces, velocity, etc. as a function of penetration distance are derived for the conical projectile under normal impact. Good correlation between the theory and experiment is obtained.

1. NOMENCLATURE

a_3	= radius of projectile body	t	= time
F	= force[3]	v	= instantaneous projectile velocity[5]
h_o	= original thickness of target plate	Δv	= projectile velocity drop
L	= line loading on projectile[3]	x	= penetration distance in axial direction
$M(x)$	= effective mass of target plate		
M_r	= radial momentum of one petal	α	= semi-vertex angle of projectile cone
$M_t(x)$	= axial component of plate momentum	β	= angle of inclination of resultant line loading
m	= projectile mass		
n	= number of petals	ξ	= instantaneous axial displacement of generic particle
r	= instantaneous radius to generic particle[4]	ρ	= mass density of target plate

2. INTRODUCTION

At the present time there are considerable theoretical and experimental data on the penetration and perforation of thick and moderately thick plates. Such information consists of resistance functions and limit velocities (minimum velocity required for complete perforation) for various projectile-plate combinations. Many of these data were collected by Bleakney and the Ballistic Research Group (1)[6] at Princeton University during World War II. Unfortunately, the work of this and similar groups was discontinued at the end of the war, so that the problem of thin plate perforation was never adequately investigated. It was through the efforts of the Pitman Dunn Physics Research Laboratory that this type of investigation was revitalized.

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[3] Subscripts A and r refer to axial and radial directions.

[4] Subscripts o, lim, and min refer to original, maximum and minimum radii.

[5] Subscript s refers to striking velocity.

[6] The boldface numbers in parentheses refer to the references appended to this paper.

The thin skin construction of present day airplanes makes an understanding of the mechanics of thin plate perforation essential. However, because of the relatively few measurable manifestations of perforation and the extremely small time intervals associated with them, detailed experimentation is outside the realm of present day techniques. Thus the bulk of the task must be undertaken from a theoretical point of view. Moreover, since this perforation process furnishes a useful experimental technique for the understanding of cracking and material properties at high loading rates, a detailed analysis is extremely important.

Former theoretical approaches to this problem, such as the works of Thomson (2) and Taylor (3), have been concerned chiefly with energy transformations or with idealized models. Taylor (3) and Bethe (4) both used the concept of an expanding hole to evaluate the work required for perforation. Since the difficulties of the problem prohibit

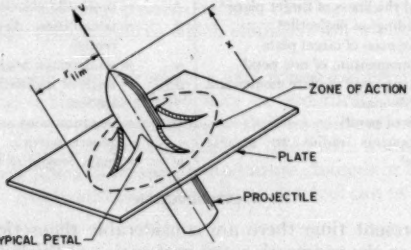

FIG. 1.

an exact analysis, a simplified model is desirable. However, the evaluation of the energy terms in any realistic model leads to a multitude of complicating factors, such as energies due to crack formation, elastic wave propagation, plastic wave propagation and plastic deformation, friction and heating, and strain rate effects.

The above mentioned work has shown good progress toward a general understanding and explanation of the phenomena. In addition as the various effects are better understood they can be added to the theory without any change in the basic framework.

Taking a momentum approach and in addition assuming a plate deformation pattern, which combines all of the above mentioned factors, one can obtain a complete solution to the perforation problem. As should be expected this solution is no better than the deformation on which it is based. It is the purpose of this paper to indicate a reasonable pattern and provide experimental confirmation of the choice. In addition some remarks are made to indicate a technique for refining this assumption.

3. GENERAL MOMENTUM ANALYSIS (5, 6)

Since disturbances propagate at a finite rate, it is apparent that penetration effects are initially restricted to lie within a zone bounded by the traveling wave front. With references to Fig. 1, let r_{lim} be the radius of a circle large enough to encompass this "zone of action" throughout the entire perforation process. Although the theory includes the effects of edge reflections for reasons of geometric simplicity a plate sufficiently large to prevent such reflections will be assumed in the following analysis.

For the system bounded by r_{lim} the absence of external forces implies conservation of momentum. This can be expressed as

$$mv_s = mv + M_t(x). \tag{1}$$

From Eq. 1, the instantaneous velocity can be evaluated as a function of penetration distance if $M_t(x)$ is known. This value could be determined if a series of instantaneous photographs could be obtained during the perforation process, as illustrated in Fig. 2.

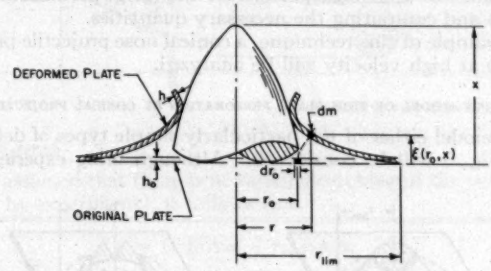

FIG. 2.

In this paper only the problem of normal impact of a relatively thin plate will be considered. It is noted, however, that the general method of analysis is by no means limited by these conditions. Because of the axial symmetry which results from normal impact, all motion can be visualized in the r, ξ plane. Thus the momentum in the x direction, of the particles originally located in the undeformed annulus, is given by

$$dM_t = 2\pi\rho h_o r_o \xi dr_o. \tag{2}$$

Since the projectile displacement x is a monotonic function of time, this displacement may be considered the independent variable of the problem. The particle velocity in the x direction is

$$\dot{\xi} = \frac{\partial \xi}{\partial x}\frac{dx}{dt} = v\frac{\partial \xi}{\partial x}. \tag{3}$$

Therefore

$$M_t = 2\pi\rho h_o \int_{r_{o_{min}}}^{r_{lim}} v r_o \frac{\partial \xi(r_o, x)}{\partial x}\, dr_o. \tag{4}$$

An effective target mass is defined as

$$M(x) = \frac{M_t}{v} = 2\pi\rho h_o \int_{r_{o_{min}}}^{r_{lim}} r_o \frac{\partial \xi(r_o, x)}{\partial x}\, dr_o. \tag{5}$$

By Eqs. 1 and 5,

$$\Delta v = v_s - v = \frac{M(x)}{m} v. \tag{6}$$

From Eq. 6, the acceleration and displacement may be obtained by differentiation and integration, respectively. Equation 6 would be an exact solution of the perforation problem if the function $\xi(r_o, x)$ could be determined exactly. At the present time, in the absence of the exact values for $\xi(r_o, x)$, a good approximate solution may be obtained by assuming a plausible kinematic pattern for the (large permanent) deformtion $\xi(r_o, x)$ and computing the necessary quantities.

As an example of this technique, a conical nose projectile perforating a thin plate at high velocity will be analyzed.

4. SIMPLE MODEL OF THIN PLATE PERFORATION BY CONICAL PROJECTILES

In this model either of the particularly simple types of deformation shown in Fig. 3 will be considered. Although firing experience indi-

FIG. 3.

cates that thin plates almost invariably fail by petalling rather than dishing, it is significant that the following theory applies whether or not petalling occurs.

For this example, it is assumed that the plate is either undeformed or, where the projectile constraint requires it, the plate assumes the shape of the projectile profile. For example, a conical projectile would cause the deformation pattern illustrated in Fig. 4. Thus a kinematic pattern which gives the minimum displacement consistent with the constraint has been assumed.

Motivation for this assumption comes from noting that inertia

effects should predominate over material strength for high speeds. Thus it is expected that the target will behave like a "limp rag" over the entire deformed region, or at least in the vicinity of the projectile-target plane intersection. Since the plastic waves have not had sufficient time to radiate any appreciable distance, the non-intersected part of the target plate remains essentially undeformed.

From the foregoing statements, it is obvious that the model chosen will be inaccurate for sufficiently low striking velocities, but will become increasingly accurate as these velocities increase. Furthermore, it is expected that this model forms the lower limit to which the actual results will converge for sufficiently high striking velocity.

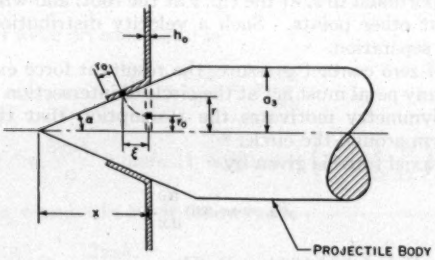

FIG. 4.

a. Velocity Drop

If it is assumed that there is no radial stretching of the petals (which is verified by experiment), it follows that

$$\xi = (x \tan \alpha - r_o) \cos \alpha. \tag{7}$$

By substitution of Eqs. 5 and 7 into 6, there results

$$\Delta v(x) = \frac{\pi \rho h_o (x \tan \alpha)^2}{m} v \sin \alpha. \tag{8}$$

This is merely the ratio of the displaced target mass to the projectile mass times $v \sin \alpha$. For sufficiently small Δv, the velocity v in Eq. 8 can be replaced by the striking velocity v_s.

In work to be reported later, it will be shown that the entire perforation phenomenon for normal impact is complete as soon as the body of the projectile intersects the target plane. Δv_{total} is the value of Δv when the projectile body intersects the target. Thus

$$\Delta v_{total} \approx \frac{\pi \rho h_o a_3^2}{m} v_s \sin \alpha. \tag{9}$$

b. Forces on Projectile

According to the assumed kinematic model all the particles in the deformed target plate move along the generators of the cone with a velocity proportional to the projectile velocity. Therefore both the projectile and the petal must be decelerating. Since negative pressures are not possible, this leads to the conclusion that the contact pressure must be zero.

Although the assumed kinematic model can be exact only if $\Delta v \to 0$, it is expected to be reasonably close for $\Delta v \ll v$. It should be noted that an exact solution for the "limp rag" model would lead to a variable normal velocity along the entire length of the petal. This velocity would be proportional to v_s at the tip, v at the root, and will be between these limits at other points. Such a velocity distribution leads to a natural petal separation.

Because of zero contact pressure, the resultant force exerted by the projectile on any petal must act at the circle of intersection of the target and cone. Symmetry motivates the assumption that this resultant force is uniform around the circle.

The total axial force is given by

$$F_A = -mv\frac{dv}{dx}. \tag{10}$$

By combining Eqs. 6 and 10 there results

$$F_A = \frac{dM(x)}{dx}v^2\left(\frac{v}{v_s}\right). \tag{11}$$

When $\Delta v \ll v$,

$$F_A \approx v_s^2\frac{dM}{dx}. \tag{12}$$

It should be noted that Eqs. 11 and 12 hold for any projectile shape or assumed kinematic model.

By using Eqs. 6 and 8 for the case being considered, Eq. 12 becomes

$$F_A \approx 2\pi\rho h_s v_s^2 x \tan^2\alpha \sin\alpha. \tag{13}$$

The axial "line loading" or axial force per unit circumferential length is

$$L_A = \frac{F_A}{2\pi x \tan\alpha} \approx \rho h_s v_s^2 \tan\alpha \sin\alpha. \tag{14}$$

To obtain the radial component of force on the petal, it is observed from Fig. 4 that

$$r = (x - \xi)\tan\alpha. \tag{15}$$

By Eqs. 7 and 15 the radial petal velocity is

$$\dot{r} = v \tan \alpha(1 - \sin \alpha). \tag{16}$$

Since the radius of the root circle is $x \tan \alpha$, each petal mass is

$$M_{petal} = \frac{\pi \rho h_o (x \tan \alpha)^2}{n} \tag{17}$$

where n is the number of petals. The radial momentum of each petal is

$$M_r = \frac{\pi \rho h_o}{n} (x \tan \alpha)^2 v \tan \alpha(1 - \sin \alpha). \tag{18}$$

The radial force on each petal is

$$F_r = \frac{dM_r}{dt} = v \frac{dM_r}{dx} \tag{19}$$

or

$$F_r = \frac{2\pi \rho h_o}{n} x \tan^2 \alpha \, (1 - \sin \alpha) \, v^2 \left(1 + \frac{x}{2v} \frac{dv}{dx}\right). \tag{20}$$

Using Eqs. 6 and 8 in 20, it follows that

$$F_r = \frac{2\pi \rho h_o}{n} x \tan^2 \alpha \, (1 - \sin \alpha) v^2 \left(\frac{v}{v_s}\right). \tag{21}$$

When $v \approx v_s$

$$F_r = \frac{2\pi \rho h_o}{n} \tan^2 \alpha \, (1 - \sin \alpha) \, v_s^2 \, x. \tag{22}$$

For this case the radial line loading is

$$L_r = \frac{F_r}{\frac{2\pi x \tan \alpha}{n}} = \rho h_o \tan^2 \alpha \, (1 - \sin \alpha) \, v_s^2. \tag{23}$$

The resultant line loading is given by

$$L = \sqrt{L_r^2 + L_A^2} = \rho h_o v_s^2 \tan^2 \alpha \sqrt{2(1 - \sin \alpha)}. \tag{24}$$

The angle of inclination of L from the projectile axis is

$$\tan \beta = \frac{L_r}{L_A} = \frac{1 - \sin \alpha}{\cos \alpha} \tag{25}$$

from which it follows that

$$\beta = \frac{\pi}{4} - \frac{1}{2} \alpha. \tag{26}$$

c. Experimental Correlation[7]

The preceeding theory has led to expressions for several quantities of interest. Because of the high velocities and small time intervals associated with the phenomenon, it is difficult to make the desired continuous measurements. However, certain extremely valuable experimental checks can and have been made in conjunction with this work.

Photographs of petal growth for conical projectiles are shown in Fig. 5. These are made from separate photographs of many firings with

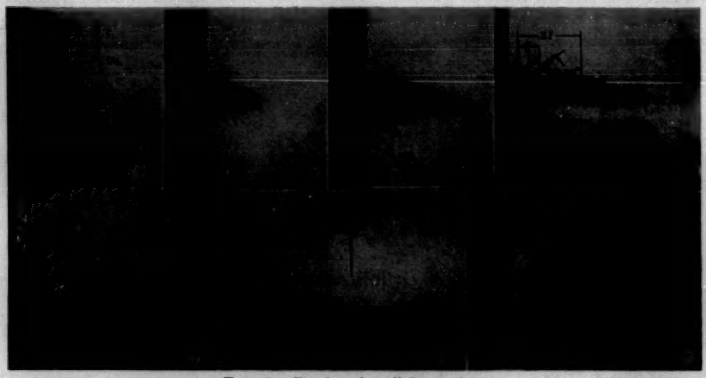

FIG. 5. Petal and spall formation.

For 20°, 111 grams, SAE 1010 steel projectile against 0.051 aluminum target. Striking velocity (v_s) = 2980 ft. per sec. Made from single exposures of several firings under identical conditions.

identical projectile-plate combinations at essentially the same striking velocities. The petal kinematics is essentially the same as that assumed in this paper. As explained previously, any slight petal curl will lead to zero contact pressure and only slight variations in Δv.

It is noted that the petals fly free as the projectile body intersects the target. As stated earlier, it was assumed that for this simple model the petals received a negligible amount of momentum after the body intersects the target. This implies that the petals retain their last momentum before separation. Thus the free axial petal velocity should be $v \sin \alpha$, the radial velocity $v \tan \alpha \ (1 - \sin \alpha)$, and the angle β indicating the direction of force and free flight is $\frac{1}{2}\left(\frac{\pi}{2} - \alpha\right)$. For the case of $\alpha = 20°$, $v_{\substack{petal \\ axial}} = 0.34\, v_{proj.}$ and $\beta = 35°$. Neglecting air resistance, which is a valid assumption during very short time intervals, the root of the petals should continue along the extension of the cone generators.

[7] The experimental firings were carried out at Pitman Dunn Laboratories, Frankford Arsenal, by Mr. J. Kymer.

Figure 5 shows the excellent experimental agreement with these theoretical results.

Experiments were made to justify the assumption of no radial petal stretching. These consisted of rolling back the deformed petals after firing tests. The results confirmed the assumption and will be discussed in later work.

A transmission ballistic pendulum was used to evaluate the total projectile velocity drop. This is a device that measures directly the projectile momentum loss minus the spall momentum gain. The spall mass was evaluated by weighing the targets before and after perforation. The spall velocity was obtained from the equation $v_{\substack{spall \\ axial}} = v \sin \alpha$, which was verified by many photographs similar to Fig. 5. The spall and pendulum momenta were added and a plot of $\frac{\Delta v_{actual}}{(\Delta v / v_s)_{theory}}$ *vs.* v_s is shown in Fig. 6. The correlation is excellent in the region of sufficiently high

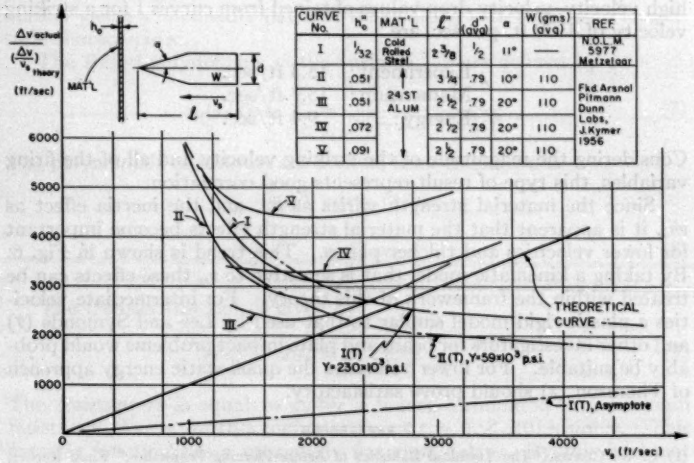
CURVE No. | h_o" | MAT'L | ℓ" | d" (avg) | α | W (gms) (avg) | REF
I | 1/32 | Cold Rolled Steel | 2 3/8 | 1/2 | 11° | — | N.O.L. M. 5977 Metzelaar
II | .051 | 24 ST ALUM | 3 1/4 | .79 | 10° | 110 | Fkd. Arsnol Pitmann Dunn Labs, J. Kymer 1956
III | .051 | | 2 1/2 | .79 | 20° | 110 |
IV | .072 | | 2 1/2 | .79 | 20° | 110 |
V | .091 | | 2 1/2 | .79 | 20° | 110 |
Δv actual / (Δv/v_s theory) (ft/sec)
MAT'L
W
d
v_s
ℓ
6000
5000
4000
3000
2000
1000
0
1000
2000
3000
4000
v_s (ft/sec)
THEORETICAL CURVE
I(T) Y=230×10³ p.s.i.
II(T), Y=59×10³ p.s.i.
I(T), Asymptote

FIG. 6. Correlation between experiments and theory.

v_s. It should be noted that since increased plate thickness leads to a non-negligible strength effect, curve V deviates slightly from the theoretical curve in the velocity range under consideration.

Curves I (T) and II (T) were plotted from results obtained by Thomson (2). This work was taken since it represents one of the most complete and recent energy solutions which can be used to predict velocity and force–time relationships without the need for extensive firing data. In this case it can be shown that the associated friction

term is negligible so that only the ultimate stress, Y, need be assumed. Since the magnitude of this stress has not been determined for very high temperatures and strain rates a value was chosen to make the experimental and Thomson curves match as well as possible. Only two Thomson curves were plotted for purposes of clarity, but the rest show the same type of correlation. In general the energy approach, with a modified ultimate stress, yields good accuracy at the lower speeds, but becomes increasingly inaccurate with increased striking velocity.

This type of correlation is due to the inherent quasi-static approach which properly accounts for the strength effects but not for all of the high velocity effects indicated in the introduction.

A further comment on the previously mentioned close correlation between theory and experiment can be made at this point. The vertical spread between the experimental, momentum, and energy curves is greatly magnified due to the multiplication of the theoretical and experimental velocity drop ratio by the striking velocity. Typical high velocity–velocity drop values obtained from curves I for a striking velocity of 3500 ft. per sec. are

Experiment:	15.3 ft/sec.
Momentum:	13.7 ft/sec.
Energy:	9.4 ft/sec.

Considering the magnitude of the striking velocity and all of the firing variables, this type of result represents good correlation.

Since the material strength varies as h_o^2, and the inertia effect as vh_o, it is apparent that the material strength effects become important for lower velocities and thicker plates. This trend is shown in Fig. 6. By taking a kinematic model that is sensitive to v_s, these effects can be treated within the framework of this theory. For intermediate velocities a plastic-rigid model similar to that used by Lee and Symonds (7) and other investigators for beam and plate impact problems would probably be suitable. For lower velocities the quasi-static energy approach of Thomson (2) should prove satisfactory.

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ADDITIONAL TABLES FOR DESIGN OF OPTIMUM LADDER NETWORKS *

BY

LOUIS WEINBERG [1]

Part II**

IV. MAXIMALLY FLAT TIME DELAY: BESSEL POLYNOMIALS (7, 8, 9)[2]

The preceding two sets of polynomials were used in the approximation of a desired *magnitude* characteristic. However, the nonlinear phase characteristic of both approximations and the resulting variation of the time delay preclude their use where a constant time delay is a paramount requirement. For such time-delay filters an excellent approximation is given by the use of *Bessel polynomials*. This approximation yields a maximally flat time delay along with a low-pass magnitude characteristic.

The Bessel polynomials in the variable $1/s$ are defined by

$$y_n(1/s) = \sum_{k=0}^{n} = \frac{(n+k)!}{(n-k)!\,k!\,(2s)^k}. \tag{7}$$

The polynomials of interest are derived from the above as

$$\begin{aligned} h_n(s) &= s^n y_n(1/s) \\ &= \sum_{k=0}^{n} a_k s^k. \end{aligned} \tag{8}$$

The transfer function is given by

$$Z_{21}(s) = \frac{H}{h_n(s)}. \tag{9}$$

The constant H is equal to a_0 for a ladder terminated in a one-ohm resistance, that is, for this configuration at $s = 0$, $Z_{21}(0)$ is unity. This transfer function has a maximally flat time delay. By this is meant that the time delay t_d is given by a function of the form

$$t_d = -\frac{d\theta}{d\omega} = \frac{t_0(b_0 + b_1\omega^2 + b_2\omega^4 + \cdots + b_{n-1}\omega^{2n-2})}{b_0 + b_1\omega^2 + b_2\omega^4 + \cdots + b_{n-1}\omega^{2n-2} + b_n\omega^{2n}}, \tag{10}$$

* This paper is based on the author's report with the same title, Technical Memorandum No. 434, Hughes Research Laboratories, Culver City, Calif.

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** Part I appeared in this JOURNAL for July, 1957.

[2] The boldface numbers in parentheses refer to the references appended to Part II of this paper.

where θ is the phase of $Z_{21}(j\omega)$, and t_0 is the zero-frequency time delay. It is noted that the first $(n-1)$ coefficients of the denominator are equal to the corresponding coefficients of the numerator. Therefore the Maclaurin series for t_d obtained by dividing the numerator by the denominator, namely,

$$-\frac{d\theta}{d\omega} = t_0\left(1 - \frac{b_n}{b_0}\omega^{2n} + \frac{b_1 b_n}{b^2_0}\omega^{2n+2} - \cdots\right), \tag{11}$$

will have the first $(n-1)$ derivatives of t_d (considered as a function of ω^2) at $\omega = 0$ equal to zero. Thus the time delay is as flat as possible in the vicinity of $\omega = 0$; hence the term maximally flat time delay. The delay is very closely equal to t_0, the zero-frequency value, up to a certain frequency (which is an increasing function of n), and then declines smoothly for values greater than this frequency.

To determine the value of n to use for satisfying a specific requirement, it is necessary to have expressions for the magnitude and time delay. We give here the exact expressions in terms of Bessel functions of half an odd integer;[3] but most often the values of the magnitude and time delay for varying n given in Table VIII suffice so that the need

TABLE VIII.—*Significant Values of u for Time Delay and Loss Characteristic of a Maximally Flat Time-Delay Network.*

a) Time-Delay Table: Giving Frequencies (u) at which Time Delay Deviates a Specified Value from its Zero-Frequency Value

n	u for 1% deviation	u for 10% deviation	u for 20% deviation	u for 50% deviation
1	0.10	0.34	0.50	1.00
2	0.56	1.09	1.39	2.20
3	1.21	1.94	2.29	3.40
4	1.93	2.84	3.31	4.60
5	2.71	3.76	4.20	5.78
6	3.52	4.69	5.95	6.97
7	4.36	5.64	6.30	8.15
8	5.22	6.59	7.30	9.33
9	6.08	7.55	8.31	10.50
10	6.96	8.52	9.33	11.67
11	7.85	9.49	10.34	12.84

b) Loss ($L = -20 \log |Z_{21}(ju)|$, in db) Table: Giving Frequencies (u) at which Loss is a Specified Number of db Down from its Zero-Frequency Value

n	u for 1/50 db	u for 1/20 db	u for 1/10 db	u for 1/5 db	u for 1/2 db	u for 1 db	u for 3 db
1	0.07	0.11	0.14	0.21	0.35	0.51	1.00
2	0.11	0.18	0.26	0.36	0.57	0.80	1.36
3	0.14	0.23	0.34	0.48	0.75	1.05	1.75
4	0.17	0.28	0.40	0.56	0.89	1.25	2.13
5	0.20	0.32	0.45	0.64	1.01	1.43	2.42
6	0.22	0.36	0.50	0.71	1.12	1.58	2.70
7	0.24	0.39	0.54	0.77	1.22	1.72	2.95
8	0.26	0.41	0.59	0.83	1.31	1.85	3.17
9	0.28	0.44	0.62	0.88	1.40	1.97	3.39
10	0.30	0.47	0.66	0.93	1.48	2.08	3.58
11	0.31	0.49	0.69	0.98	1.55	2.19	3.77

for using the exact analytical form is eliminated. The time delay is given by

$$t_d = t_0\left[1 - \frac{1}{u^2\left(\frac{\pi}{2u}\{J^2_{-n-\frac{1}{2}}(u) + J^2_{n+\frac{1}{2}}(u)\}\right)}\right] \tag{12}$$

[3] Tables for these functions are given in "Tables of Spherical Bessel Functions," 2 vols., NBS, Math. Tables Project, Columbia University Press, 1947. The particular combination of the spherical Bessel functions that occurs in the magnitude and phase functions is tabulated in Table 13 of "Scattering and Radiation from Circular Cylinders and Spheres, Tables of Amplitude and Phase Angles," Office of Research and Inventions, U. S. Navy Department, July, 1946.

and the magnitude is

$$|Z_{21}(ju)| = \frac{H}{u^{n+1}\left\{\frac{\pi}{2u}\left[J^2_{-n-1}(u) + J^2_{n+1}(u)\right]\right\}^{\frac{1}{2}}}. \tag{13}$$

The loss in db, $L = -20 \log |Z_{21}(ju)|$, tends to the Gaussian form with increasing n,

$$L = \frac{10\,u^2}{(2n-1)\ln 10}. \tag{14}$$

In the above formulas u is the normalized frequency variable ω/ω_0 and J is a Bessel function.

Use of Eq. 14 gives the 3-db bandwidth as

$$u_{3db} \cong \sqrt{(2n-1)\ln 2}, \tag{15}$$

which approximation is good for $n \geq 3$.

In Table VIII are given values of u for four significant points on the time-delay curves and seven significant points on the loss curves. The element values corresponding to the values of n of 1 through 11 are given in Table IX.

Example 4.1. Design a ladder network with a delay of 0.1 μ sec and a constant loss (not greater than 1 db) up to 2.7 mc/s. The network is to be terminated in a load resistance of 2000 ohms and is to be driven by a current source.

Since $t_0 = 1/\omega_0 = 0.1$ sec., then $\omega_0 = 10^7$. For $f = 2.7$ mc/s, $\omega = 5.4\pi \times 10^6$, and $\omega/\omega_0 = 0.54\pi$, which is approximately 1.7.

Using Table VIII(b) for $u = 1.7$, we see that for $n = 7$ the loss is less than 1 db. Now by using Table VIII(a), it is shown that the time delay for $n = 7$ is constant at this frequency.

Consulting Table IX(a) we find the element values for $n = 7$; the unprimed values are used since n is odd and the input is a current source. We remove the normalization by multiplying C's by $1/R\omega_0 = 0.5 \times 10^{-10}$, and L's by $R/\omega_0 = 2 \times 10^{-4}$, and thus obtain the final network given in Fig. 9.

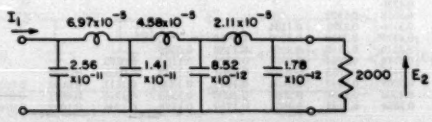

FIG. 9. Time-delay ladder obtained in Example 4.1.

TABLE IX.—*Element Values (in ohms, henrys, farads) of a Normalized Maximally Flat Time-Delay Network.*

Value of n	C_1 or L_1'	L_2 or C_2'	C_3 or L_3'	L_4 or C_4'	C_5 or L_5'	L_6 or C_6'	C_7 or L_7'	L_8 or C_8'	C_9 or L_9'	L_{10} or C_{10}'	C_{11} or L_{11}'
a) τ = 0											
1	1.0000										
2	0.3333	1.0000									
3	0.1667	0.4800	0.8333								
4	0.1000	0.2899	0.4627	0.7101							
5	0.0667	0.1948	0.3103	0.4215	0.6231						
6	0.0476	0.1400	0.2246	0.3005	0.3821	0.5595					
7	0.0357	0.1055	0.1704	0.2288	0.2827	0.3487	0.5111				
8	0.0278	0.0823	0.1338	0.1806	0.2227	0.2639	0.3212	0.4732			
9	0.0222	0.0660	0.1077	0.1463	0.1811	0.2129	0.2465	0.2986	0.4424		
10	0.0182	0.0541	0.0886	0.1209	0.1549	0.1880	0.2057	0.2209	0.2712	0.4161	
11	0.0152	0.0451	0.0741	0.1016	0.1269	0.1499	0.1708	0.1916	0.2175	0.2639	0.3955
b) τ = 1/8											
1	9.0000										
2	8.6533	0.0433									
3	7.1426	0.0615	1.3652								
4	6.0700	0.0589	2.3569	0.0127							
5	5.3229	0.0535	2.5118	0.0246	0.5401						
6	4.7803	0.0484	2.4267	0.0283	1.1309	0.00601					
7	4.3691	0.0442	2.2790	0.0288	1.3738	0.0133	0.2881				
8	4.0462	0.0407	2.1256	0.0280	1.4536	0.0168	0.6627	0.00350			
9	3.7848	0.0378	1.9841	0.0267	1.4558	0.0184	0.8666	0.00830	0.1788		
10	3.5682	0.0354	1.8591	0.0254	1.4215	0.0189	0.9718	0.0111	0.4348	0.00228	
11	3.3850	0.0334	1.7502	0.0240	1.3710	0.0188	1.0191	0.0128	0.6014	0.00589	0.1159
c) τ = 1/4											
1	5.0000										
2	4.6409	0.0898									
3	3.7994	0.1258	0.6973								
4	3.2221	0.1198	1.1956	0.0258							
5	2.8247	0.1084	1.2690	0.0498	0.2731						
6	2.5375	0.0980	1.2231	0.0571	0.5703	0.0121					
7	2.3202	0.0893	1.1470	0.0580	0.6915	0.0268	0.1451				
8	2.1496	0.0823	1.0689	0.0563	0.7306	0.0338	0.3333	0.00704			
9	2.0114	0.0764	0.9973	0.0537	0.7310	0.0369	0.4354	0.0167	0.0899		
10	1.8967	0.0716	0.9342	0.0509	0.7132	0.0379	0.4878	0.0224	0.2184	0.00459	
11	1.7999	0.0676	0.8794	0.0482	0.6875	0.0377	0.5112	0.0256	0.2998	0.0115	0.0603
d) τ = 1/3											
1	4.0000										
2	3.6330	0.1223									
3	2.9601	0.1700	0.5298								
4	2.5075	0.1613	0.9046	0.0347							
5	2.1981	0.1457	0.9577	0.0669	0.2063						
6	1.9750	0.1316	0.9217	0.0765	0.4300	0.0163					
7	1.8064	0.1199	0.8636	0.0776	0.5207	0.0358	0.1093				
8	1.6740	0.1104	0.8044	0.0753	0.5497	0.0453	0.2509	0.00942			
9	1.5667	0.1026	0.7503	0.0718	0.5496	0.0494	0.3275	0.0223	0.0676		
10	1.4777	0.0962	0.7027	0.0680	0.5360	0.0506	0.3658	0.0299	0.1642	0.00614	
11	1.4024	0.0907	0.6615	0.0644	0.5165	0.0504	0.3842	0.0342	0.2252	0.0153	0.0455
e) τ = 1/2											
1	3.0000										
2	2.6180	0.1910									
3	2.1156	0.2613	0.3618								
4	1.7893	0.2461	0.6127	0.0530							
5	1.5686	0.2217	0.6456	0.1015	0.1393						
6	1.4102	0.1999	0.6196	0.1158	0.2894	0.0246					
7	1.2904	0.1821	0.5797	0.1171	0.3497	0.0542	0.0735				
8	1.1964	0.1676	0.5395	0.1135	0.3685	0.0683	0.1684	0.0142			
9	1.1202	0.1558	0.5030	0.1081	0.3680	0.0744	0.2195	0.0336	0.0453		
10	1.0569	0.1460	0.4710	0.1024	0.3586	0.0763	0.2456	0.0450	0.1100	0.00925	
11	1.0033	0.1377	0.4433	0.0970	0.3454	0.0758	0.2570	0.0515	0.1503	0.0228	0.0309
f) τ = 1											
1	2.0000										
2	1.5774	0.4226									
3	1.2550	0.5528	0.1922								
4	1.0598	0.5116	0.3181	0.1104							
5	0.9303	0.4577	0.3312	0.2090	0.0718						
6	0.8377	0.4116	0.3158	0.2364	0.1480	0.0505					
7	0.7677	0.3744	0.2944	0.2378	0.1778	0.1104	0.0375				
8	0.7125	0.3446	0.2735	0.2297	0.1867	0.1387	0.0855	0.0289			
9	0.6678	0.3203	0.2547	0.2184	0.1859	0.1506	0.1111	0.0682	0.0230		
10	0.6305	0.3002	0.2384	0.2066	0.1808	0.1539	0.1240	0.0911	0.0557	0.0187	
11	0.5989	0.2834	0.2243	0.1954	0.1739	0.1528	0.1296	0.1039	0.0761	0.0465	0.0154

V. NORMALIZATION, DUALITY, RECIPROCITY THEOREM; FREQUENCY TRANSFORMATIONS AND TRANSFORMATION OF SYMMETRICAL NETWORKS

Normalization

The element values in the tables are normalized with respect to the load resistance R_1 and the radian frequency. In other words, the value of R_1 is considered as one ohm and that of the cutoff frequency (or $\omega_0 = 1/t_0$ for the time-delay networks) is one radian per second. These frequency and impedance normalizations may be removed simply.

Since the impedance of the three different kinds of elements appearing in a network is given respectively by R, Ls, and $1/Cs$, we note that if the frequency is multiplied by a constant the resistance is unaffected, but that to maintain the impedance of the inductance and capacitance invariant, it is necessary to *divide* L and C by the same constant. This provides the simple rule for removal of the frequency normalization: to raise the radian frequency $\omega = 1$ to $\omega = \omega_c$, divide all L's and C's in the network by ω_c. On the other hand, to raise the impedance level by a factor H we must multiply the impedance of each type of element by this factor, that is, *multiply* every R and L in the network by H, and *divide* every C by H. Thus we see only simple multiplications are involved.

The two rules may be combined into one operation: to raise the radian frequency to ω_c and the impedance level by H, we multiply every resistance by H, every inductance by H/ω_c, and every capacitance by $1/(\omega_c H)$.

Duality

The dual of a ladder network may always be realized simply. The impedance of every series arm is replaced by the admittance of a shunt arm, and vice versa. In simpler terms, this means that every capacitance of C farads is replaced by the dual element which is an inductance of C henrys, every inductance of L henrys is replaced by a capacitance of L farads, and every resistance of R ohms becomes a conductance of R mhos; if the original element is a series arm then the dual element becomes a shunt arm, whereas if the original element is a shunt arm then the dual element is a series arm. For example, the dual of the network in (*a*) of Fig. 10 is given by the one in (*b*).

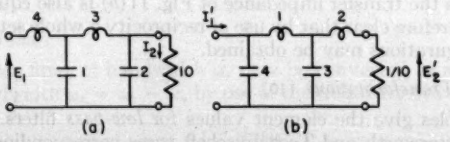

FIG. 10. Ladder network and its dual (values in ohms, henrys, and farads).

What are the characteristics of the dual network with respect to that of a given network? The impedances (admittances) of one network (both transfer and driving-point) become admittances (impedances) of the other. Thus in Fig. 10(*a*) the input is a voltage source and the output a current so that the transfer function is the admittance $Y_{21} = I_2/E_1$. In the dual given by Fig. 10(*b*) the transfer impedance $Z'_{21} = E_2'/I_1'$ is the same rational function as Y_{21} of (*a*).

It is therefore clear that the primed and unprimed values lead to dual networks.

Reciprocity Theorem

Often a network designed by the use of the tables does not have the configuration demanded in a particular problem. For example, a shunt capacitance may be desired at the output and a resistance at the input, but the network obtained has the form shown in Fig. 11(*a*). By the

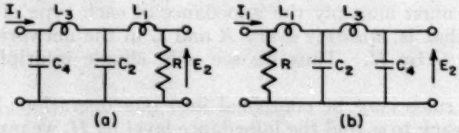

FIG. 11.—Ladder network and one obtained from it by use of reciprocity theorem.

use of the reciprocity theorem the network of Fig. 11(*b*) with the desired configuration may be obtained.

The reciprocity theorem states that the transfer impedance (or transfer admittance) remains unchanged if the excitation and measuring instrument change places. Thus in Fig. 11(*a*) we have the transfer impedance

$$Z_{21} = \frac{E_2}{I_1} = \frac{p(s)}{q(s)}, \tag{16}$$

where the excitation is a current source I_1 flowing into the input terminals and the output is a voltage (measured by a voltmeter across R). Now if the current source is placed across R and the voltmeter placed across C_4, then the conditions of the reciprocity theorem have been satisfied. Thus the transfer impedance of Fig. 11(*b*) is also equal to p/q.

It is therefore clear that by use of reciprocity a whole set of new network configurations may be obtained.

Frequency Transformations (10)

The tables give the element values for *low-pass* filters. However, for the Butterworth and Tschebyscheff cases corresponding characteristics may be obtained for the *high-pass*, *band-pass*, and *band-elimination*

filters by the use of transformations of the frequency variable. These transformations do not work for the Bessel-polynomial case because the distortion of the frequency-variable scale makes the phase characteristic nonlinear as a function of the new frequency variable.

High-Pass Filters

A normalized low-pass filter characteristic is shown in Fig. 12(*a*); the corresponding high-pass characteristic is given in Fig. 12(*b*). The

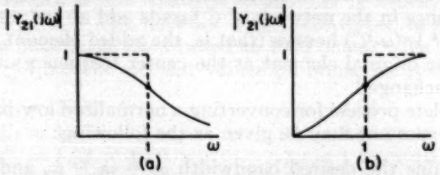

FIG. 12. Low-pass characteristic and the corresponding high-pass one obtained by a frequency transformation.

latter characteristic may be obtained from the former by the use of the transformation $s' = 1/s$. Since by use of this transformation the impedance of an inductance Ls becomes the impedance L/s', the impedance of a capacitance $1/Cs$ becomes s'/C, and the value of a resistance remains unchanged, a simple rule for converting a low-pass ladder network to a high-pass one may be formulated. The rule is: replace every inductance of L henrys by a capacitance of $1/L$ farads; replace every capacitance of C farads by an inductance of $1/C$ henrys; and leave the resistances unchanged. Thus if the network in Fig. 13(*a*) has a low-pass

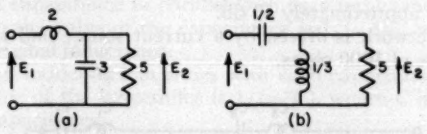

FIG. 13. Low-pass network and its corresponding high-pass network.

characteristic, then the corresponding high-pass network is given in Fig. 13(*b*).

Band-Pass Filters

A low-pass filter of bandwidth ω_c may be converted to a band-pass filter of bandwidth $\omega_c = \omega_b - \omega_a$ by use of the frequency transformation

$$s = \frac{(s')^2 + \omega_0^2}{s'}. \tag{17}$$

Thus the right-hand side of Eq. 17 is substituted for every s in the transfer function. Here ω_b is the upper frequency limit and ω_a is the lower frequency limit of the band, while ω_0 is the center frequency of the band. The band limits have geometric symmetry about the center frequency, that is, $\omega_a\omega_b = \omega_0^2$.

However, it is not necessary to actually carry out the functional transformation, since there is a simple rule for converting the low-pass network to a band-pass one: for each inductance in the network of L henrys add a capacitance in series with it of value $1/(\omega_0^2 L)$ farads; for each capacitance in the network of C farads add an inductance in parallel with it of $1/(\omega_0^2 C)$ henrys (that is, the added element always resonates with the original element at the center frequency ω_0); leave the resistances unchanged.

The complete process for converting a normalized low-pass filter to a desired band-pass one may be given as the following:

1. Determine the desired bandwidth $\omega_c = \omega_b - \omega_a$ and the desired center frequency $\omega_0^2 = \omega_a\omega_b$ from the given data.
2. Change the bandwidth of the low-pass filter to ω_c.
3. Perform the low-pass to band-pass transformation on the network.
4. Remove the level normalization from the resulting band-pass filter.

Example 5.1. Design an equal-ripple band-pass filter with the following characteristics:

(*a*) The ripple in the pass band is 1 db.
(*b*) The center frequency is $f_0 = 1000$ cps.
(*c*) The bandwidth f_c measured at 1-db points is 100 cps.
(*d*) At the frequencies corresponding to three times f_c the response is to be down approximately 50 db.
(*e*) The network is driven by a current source and should have a load resistance of 1000 ohms.

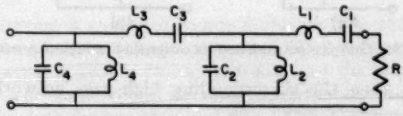

FIG. 14. Band-pass filter for Example 5.1.

In order to design this filter it is not necessary to find the actual frequencies at which the response is down 1 db and 50 db, but if we wished to find them we could use the formulas $f_a f_b = f_a(f_a + 100) = 10^6$ and $f_{50}(f_{50} + 300) = 10^6$, where f_a is the lower 1-db frequency and f_{50} is the lower 50-db frequency.

From Table V we find that the 1-db ripple corresponds to $\epsilon = 0.5088$. We now calculate n and find that $n = 4$ yields approximately 49-db attenuation at $\omega = 3$. Therefore using $n = 4$ and the primed values of Table V(a), we find the element values:

$$L_1' = 1.0495 \qquad L_2' = 1.9093$$
$$C_3' = 1.4126 \qquad C_4' = 1.2817$$

The bandwidth is now changed to $\omega_c = 2\pi \times 100$ by dividing the above values by ω_c. The network is then converted to the band-pass form and the impedance level raised to 1000 ohms. The final network given in Fig. 14 has the element values (in ohms, henrys, and farads):

$$R = 1000 \qquad L_3 = 3.04$$
$$L_1 = 1.67 \qquad C_3 = 8.33 \times 10^{-9}$$
$$C_1 = 1.52 \times 10^{-8} \qquad L_4 = 1.15 \times 10^{-2}$$
$$L_2 = 1.41 \times 10^{-2} \qquad C_4 = 2.20 \times 10^{-6}$$
$$C_2 = 2.25 \times 10^{-6}$$

Band-Elimination Filters

The transformation from a low-pass to a band-elimination characteristic is given by

$$s = \frac{s'}{(s')^2 + \omega_0^2}. \tag{18}$$

As for the band-pass filter the transformation can be achieved by direct operation on the low-pass network. The rule follows:

(a) Add a capacitance in parallel with each inductance in the low-pass network; the value of the capacitance is $1/(\omega_0^2 L)$, where L is the value of the original inductance.

(b) Add an inductance in series with each capacitance of the network; the value of the inductance is $1/(\omega_0^2 C)$, where C is the value of the original capacitance.

(c) Since the resistances are unaffected by the transformation, their values are not changed.

Transformation of Symmetrical Networks

It has been pointed out that the Butterworth and Tschebyscheff networks obtained for $r = 1$ and n odd are symmetrical. This symmetry allows any specified resistance ratio to be obtained simply; the method used transforms the symmetrical network to an unsymmetrical one with the desired resistance ratio.

If the symmetrical network is divided as shown in Fig. 15, then the

over-all transfer impedance is given in terms of the impedances of the component networks by (11)

$$Z_{21} = \frac{Z_{21a}Z_{21b}}{Z_a + Z_b}. \tag{19}$$

The subscripts a and b have been used to designate the networks on the left and right, respectively. But because of the symmetry, the component networks are the same and consequently $Z_{21b} = Z_{21a}$ and $Z_b = Z_a$. Now suppose it is desired to increase the resistance ratio by r. If the impedance level of N_a is multiplied by r, the desired effect will have been accomplished. But this change also increases Z_{21a} and Z_a by r. Because $Z_b = Z_a$, however, the Z_{21} of the whole network is not changed

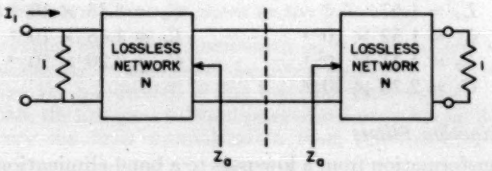

FIG. 15. Decomposition of a symmetrical network into two network halves.

except by a constant multiplier. For example, if $r = 10$ then the transfer impedance before the level change is

$$Z_{21} = \frac{(Z_{21a})^2}{2Z_a}, \tag{20}$$

whereas after the change it is

$$Z'_{21} = \frac{10(Z_{21a})^2}{11Z_a}, \tag{21}$$

which differs from Eq. 20 only by a constant multiplier.

An analogous situation of course holds for transfer admittances.

Thus it is possible to obtain two different networks with the same value of r; one is derived from the table for the desired value of r, and the second, as indicated above, by means of a transformation of a symmetrical network, the symmetrical network being obtained from the table for $r = 1$. For example, for the transfer impedance of a Tschebyscheff network with $n = 3$, $r = 1/2$, and a 1/10-db ripple, the network shown in Fig. 16 is obtained from Table II(*e*). However, if Table II(*f*) is used the symmetrical network in Fig. 17(*a*) results; multiplying the impedance level of the left half of this network by 1/2 yields the network

of Fig. 17(*b*), for which r is now 1/2. Inspection of the networks in Figs. 16 and 17(*b*) shows that they differ, even though their transfer

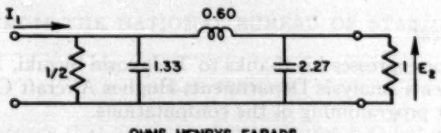

FIG. 16. Normalized Tschebyscheff network with $r = 1/2$, $n = 3$, and 1/10-db ripple.

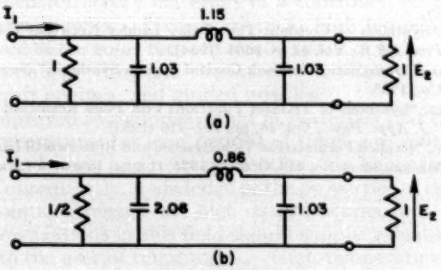

FIG. 17. Normalized Tschebyscheff network with $n = 3$, and 1/10-db ripple; (*a*) $r = 1$; (*b*) $r = 1/2$ achieved by an impedance level change on half the network.

impedances are *identical*. The reason for this is that the tables are derived for a network reflection coefficient all of whose zeros lie in *only one* half-plane, whereas the network obtained by transformation of the symmetrical network has the zeros of its reflection coefficient alternating in the left and right half-planes. This phenomenon has important implications and is discussed elsewhere (12).

CONCLUSION

The design of three classes of practical networks with resistance terminations at both ends becomes simple by use of the tables presented in this paper. The tables give the element values for the normalized low-pass network with a Butterworth, Tschebyscheff, or Bessel-polynomial characteristic. The low-pass networks that are realized in the Butterworth and Tschebyscheff cases can also be easily transformed to serve high-pass, band-pass, or band-elimination functions.

In the future tables will be presented for networks with uniform dissipation and for networks whose reflection coefficients possess zeros that alternate in the left and right half-planes.

Acknowledgment

The author expresses his thanks to Tadayoshi Suzuki, Mathematics Section, Systems Analysis Department, Hughes Aircraft Company, for his intelligent programming of the computations.

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NOTES FROM THE NATIONAL BUREAU OF STANDARDS

SOLAR FURNACE

A solar furnace that generates temperatures $\frac{2}{3}$ as hot as the surface of the sun has recently been acquired by the National Bureau of Standards as a new research facility in the high-temperature field. Bureau scientists are now using the furnace to produce temperatures up to 3500° C. to melt refractory materials in a controlled environment free of contaminating agents. Investigations at high temperatures carried out with the aid of the solar furnace should result in better temperature-resistant materials to withstand the extreme conditions found in atomic reactors, aircraft engines, and guided missiles.

New or improved refractories—that is, materials that can withstand very high temperatures for long periods of time—are continually being developed by industry, and new applications are being found for these products. Consequently, knowledge of the properties of these materials—melting points, strength at high temperatures, etc.—is urgently needed. Investigations in this field should supply valuable engineering information to the user of refractories. High-temperature tungsten arc or carbon resistor furnaces have commonly been employed in the past for such studies, but with the disadvantage that the crucibles, electrodes, or resistors contaminate the reaction and give false indications. However, in a solar furnace, the material itself can be its own crucible, with consequent freedom from contamination.

The Bureau's solar furnace was converted from a surplus Army searchlight with a 5-ft. diameter parabolic mirror. It collects the sun's rays and focuses them into an intensely hot spot only $\frac{1}{4}$-in. in diameter. Heating occurs only at this small spot, and the experiment is carried out here. This area can be isolated by closed glass tubing, which can be evacuated or filled with gas of the experimenter's choice. The glass enclosure is not affected by the sun's rays since the image of the sun is unfocused where the light passes through the enclosure and no local heating of the glass results.

The curved mirror faces a flat mirror, about 8 ft. square, which is directed at the sun and reflects the light into the solar furnace. This large, flat mirror, called a heliostat, is attached to a searchlight mount so that it can be turned to follow the sun through the sky as the earth turns on its axis. An assembly of photocells with appropriate electronic equipment controls the heliostat driving mechanism in response to the sun's apparent motion.

Besides study of the properties of refractory materials, the solar furnace can be used in the "zone refining" of oxides of zirconium, thorium, or uranium to produce extremely pure samples of those compounds. By means of the solar furnace it might even be possible to grow single crystals of these and similar materials for laboratory studies.

A SIMPLE TRANSISTOR BETA TESTER

A simple, inexpensive laboratory instrument for measuring the current gain, or β, of a wide variety of transistors has been developed by the National Bureau of Standards. The testing device, designed by G. F. Montgomery of the Bureau's electronic instrumentation laboratory, measures the common-emitter short-circuit current gain of *pnp* or *npn* transistors at low audio frequency.

In operation, the transistor is plugged into the instrument, and a dial is adjusted to the point where a tone is heard from a loudspeaker. The β is then read directly from the dial. Properly calibrated, the instrument can measure β accurately over a range of 10 to 170.

The circuit is similar in principle to one used for measuring vacuum tube transconductance. In such a tube circuit, part of the plate voltage is fed back into the grid through resistor and transformer coupling to cause oscillation. Similarly, with the circuit for measuring transistor gain, the output is fed back into the input through a variable resistor and a transformer; when the resistor is properly adjusted, the circuit begins to oscillate at an audio frequency. The dial on the variable resistor can be calibrated through a substitution method.

To reduce the number of controls to a minimum, circuit parameters are chosen so that the transistor will adjust itself to a specified d-c, operating point. The resistors in the circuit were selected to fix this point at about 5 volts collector potential and 1 ma collector current. For any transistor whose β falls within the measuring range of the instrument, these d-c. values will be closely approximated when the transistor is plugged in.

The frequency at which oscillations begin depends upon the characteristics of the transformer and the phase shift of β. The current ratio of the usual audio transformer has a broad maximum centered at 1 or 2 kc., and if the phase shift of the transistor is sufficiently small, oscillation begins at a frequency near this maximum. However, the transistor gain required to produce oscillation for a given dial setting is not a particularly sensitive function of frequency. Thus, measurements accurate to within a few per cent of full scale can be expected.

Elastic Moduli of Diamond.—An ultrasonic technique for accurately measuring the elastic moduli of small specimens of a wide variety of materials has been developed by H. J. McSkimin and W. L. Bond of Bell Telephone Laboratories. With suitable auxiliary equipment, the method can be applied to specimens under widely varying conditions of temperature and pressure.

Precise information on the elastic constants of materials is of importance in many fundamental studies of the solid state. Of particular interest is the diamond, since there are very few recorded measurements of its elastic moduli.

The ultrasonic technique developed at Bell Laboratories consists essentially of transmitting short trains of high-frequency mechanical waves into the specimen and determining their velocity of propagation. From these data and the known density of the specimen, the elastic moduli can be calculated. In the work with diamond, both longitudinal and shear waves were used, giving data for determining its three elastic moduli.

Flat and parallel surfaces were ground on opposite sides of the diamond, and its thickness measured very precisely. The specimen was then fastened to one end of a fused silica "buffer" rod by means of a thin film of viscous liquid. A suitable quartz transducer was attached to the opposite end of the buffer.

Repeated trains of ultrasonic waves at frequencies up to 200 mc. generated by the transducer were transmitted along the buffer rod. These wave trains were principally reflected at the buffer-specimen interface, but were also partially transmitted into the specimen and reflected back and forth between its parallel surfaces, resulting in a series of multiple reflections. At certain critical frequencies, these echoes were precisely in phase and combined to give rise to a characteristic pattern on an oscilloscope responsive to the transducer. The velocity of propagation in the specimen could then be determined from these frequencies and the thickness; and from a knowledge of the density, the adiabatic elastic constants were computed.

Two diamonds were used in these studies. Each before cutting was a natural dodecahedron of a pale yellow color and quite transparent. Both were Type I diamonds as evidenced by a strong optical absorption at 8 microns wavelength, and each was a single crystal as determined by X-ray reflection patterns.

Expressed in units of 10^{12} dynes/-cm^2, the elastic moduli were 10.76 ± 0.6 per cent for C_{11}; 1.25 ± 5.4 per cent for C_{12}; and 5.76 ± 0.3 per cent for C_{44}. While the value for C_{11} agrees reasonably well with previous measurements, the value for C_{12} is much smaller and that for C_{44} larger than other workers have reported.

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LOW-LEVEL RADIO-FREQUENCY MEASUREMENTS

BY
C. W. HARGENS[1]

Radio communications receivers developed during the past decade have been improved in sensitivity to such an extent that it is now hard to find instruments capable of testing them. It is important to be able to measure the receivers' sensitivity so that uniformity of performance can be maintained. Manufacturers of receiving equipment as well as users have always needed standards capable of performing this measurement.

A signal generator is the device commonly used to calibrate communications receivers with respect to sensitivity. New signal generators are now making their appearance with dial markings down to 0.1 microvolt. This low level of generator output is provided to calibrate the new receivers which have sensitivities below one microvolt.

One tenth of a microvolt is indeed a very low voltage, and referred to a 50-ohm transmission line represents an extremely small amount of power. When signal generators are used as calibration standards, one is interested in knowing that the indicated 0.1 microvolt has some degree of accuracy. Hence, to verify the generator dial markings it is actually necessary to be able to detect even smaller quantities, say 0.01 microvolt, for 10 per cent accuracy. Detecting 0.01 microvolt is then the problem of the man who tests the signal generator upon which all of the secondary measurements depend.

To take account of 0.01 microvolt on a 50-ohm line one must be able to detect 2×10^{-18} watt of power. This extremely small quantity is equivalent to a current of 2×10^{-10} ampere. In terms of d-c. measurements one would be able to work with a current of this order. However, at radio frequencies it is a different matter to find a device or substance which will respond as conveniently as the faithful galvanometer used in the d-c. case. Neither can such low levels be rectified by ordinary methods, employing crystals, et cetera.

An attempt is usually made to apply an integrating principle; that is, to convert the electrical oscillations to heat. The heat thus produced must be conserved and applied to a system which is thermally sensitive and stable. If for example the power of 2×10^{-18} watt were applied to heat a bolometer wire 0.001 cm. in diameter and 1 mm. long, the temperature of the wire might theoretically be caused to rise 10^{-8} deg. in an hour. Naturally it would be difficult to observe such a small thermal change, and the mass of the heated material would have to be

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reduced many orders of magnitude before a feasible arrangement resulted.

Working against measurements of this type there is also the ever-present thermal noise of the circuit. Of course noise power is dependent upon the frequency bandwidth of the circuit, and in communications receivers this band must be sufficiently broad to pass the intelligence contained in a message. This minimum bandwidth then limits the useful sensitivity of the receiver.

On the other hand, the device which is strictly for power measurement can be useful if it accepts only a single frequency. This statement is theoretically true, but again one experienced in experimental radio techniques will recognize the difficulty of working with very narrow band apparatus. Here the difficulty arises from frequency instability which is present in local oscillators and other circuits. Hence, one soon reaches a limit in noise elimination by band restriction methods.

Another method that has been used to detect and measure low-level radio-frequency signals in the presence of noise involves a cross-correlation system.[2] Such an arrangement consists of two channels, one strong and the other (the one to be measured) weak and noisy. By the use of a multiplier unit their average product can be obtained. Coherent signals are thus produced, eliminating the random noise and separating the desired frequency. The success of this method is limited, however, by difficulties which lie with the involved apparatus.

A study now under way in the Laboratories is an attempt to clarify the state of low-level R-F measuring techniques that might be applicable to the signal generator calibration problem. Novel methods are being sought, and those mentioned are being studied to find ways of standardizing low-level signal generators. The work is sponsored by the Signal Corps.

[2] K. E. MORTENSON, "How to Measure Low-Level R-F Signals," *Electronics*, Vol. 26, p. 162 (1953).

THE BIOCHEMICAL RESEARCH FOUNDATION

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EFFECT OF TYROCIDINE ON THE CARBOHYDRATE METABOLISM OF YEAST AND TUMOR TISSUE, AND ON THE GROWTH OF TUMORS IN MICE

BY

GLADYS E. WOODWARD AND MARIE T. HUDSON

On the hypothesis that inhibitors of carbohydrate metabolism might be effective in the control of cancer, a screening program has been under way in this laboratory to find such inhibitors. Anaerobic yeast fermentation has been used as the test system (1). Since yeast cells and tumor cells metabolize glucose in a similar manner anaerobically, it was assumed that an inhibitor of yeast fermentation would also be an inhibitor of the corresponding process in tumor tissue. During the course of this screening program the antibiotic, tyrocidine, was found to be one of the best inhibitors of anaerobic yeast fermentation (2). The assumption that tyrocidine would also be effective with tumor cells was verified in this laboratory by Yushok (3) when he found that the anaerobic glycolysis of ascites tumor cells was inhibited by tyrocidine in a concentration almost as low as had been found to be inhibitory with yeast cells. Further studies with tyrocidine therefore seemed warranted.

The present report describes additional studies on the effect of tyrocidine on yeast metabolism, as well as metabolic studies with tumor slices and treatment of tumor-bearing mice with tyrocidine.

EFFECT OF TYROCIDINE ON YEAST METABOLISM

Fermentation and respiration rates were measured in a Warburg manometric apparatus at 37° C. The basic reaction mixture contained 4 mg. pressed bakers' yeast (Fleischmann), sufficient glucose to give a final concentration of 0.02 M and distilled water to give a total volume of 2 ml. The gas phase was 5 per cent CO_2 in N_2 for the fermentation measurements and air for the respiration measurements. After equilibration, the yeast in aqueous suspension was tipped from the side-arm into the glucose in the main part of a flask to start the reaction.

Tyrocidine, as the hydrochloride (obtained from S. B. Penick and Co.), was but slightly soluble in water. Therefore a 10 per cent solution in ethyl alcohol was made, and this alcoholic solution was then diluted with water to a concentration (colloidal suspension) suitable to use in adding the desired amounts to the fermentation and respiration mixtures. The colloidal material was mixed with the glucose in the main part of a flask.

The data in Table I show that tyrocidine in a concentration of 0.005 per cent produced almost complete inhibition of anaerobic fermentation,

TABLE I.—*Inhibition of Anaerobic Yeast Fermentation by Tyrocidine.*

	Percentage Inhibition in Different Media			
		KH_2PO_4 0.02 M	Mixed K-Na Phosphate Buffer 0.02 M	
Tyrocidine Conc., %	Unbuffered	pH 4.5	pH 5.5	pH 6.5
0.005	96	—		
0.002	72	—		
0.001	42	61	55	59
0.00075	33	—		
0.0005	4	11		

while at a concentration of 0.001 per cent partial inhibition was produced. When phosphate buffer was included in the medium at a concentration of 0.02 M in the pH range of 4.5 to 6.5, the degree of inhibition was a little greater than in the absence of phosphate.

Tyrocidine was also found to be inhibitory to yeast respiration (oxidation of glucose). About the same concentration of tyrocidine was required to inhibit respiration (Table II) as was required to inhibit

TABLE II.—*Inhibition of Yeast Respiration by Tyrocidine.*

	Percentage Inhibition in Different Media	
Tyrocidine Conc., %	Unbuffered	0.02 M KH_2PO_4
0.0015	79	93
0.0010	61	86

fermentation, and as with fermentation the inhibitory effect was slightly greater in the presence of phosphate.

The effect of tyrocidine on yeast hexokinase, considered to be the enzyme which initiates fermentation, was tested. Although tyrocidine inhibited the hexokinase reaction (Table III), the concentration of

TABLE III.—*Inhibition of the Yeast Hexokinase Reaction by Tyrocidine.*

Tyrocidine Conc., %	Percentage Inhibition
0.1	96
0.05	58
0.02	35

tyrocidine required to produce inhibition in the range of 30 to 70 per cent was about 25 times greater than that required for equal inhibition of the complete fermentation system. It appears, therefore, that some other factor in the fermentation system must be more sensitive than hexokinase to the inhibitor.

EFFECT OF TYROCIDINE ON GLYCOLYSIS OF TUMOR SLICES

Glycolysis of tumor slices was measured in the Warburg manometric apparatus in Krebs-Ringer bicarbonate solution in an atmosphere of 5 per cent CO_2 in N_2. In order to produce appreciable inhibition of glycolysis, the amount of tyrocidine had to be increased to a concentration of 0.05 to 0.1 per cent (Table IV), and indeed at times there was no

TABLE IV.—*Effect of Tyrocidine, Alone and in Combination, on Glycolysis of Tumor Slices.*

Tumor*	Tyrocidine Conc., %	Additional Compound		Percentage Inhibition of Glycolysis		
		Name	Conc., %	Tyrocidine Alone	Compound Alone	Tyrocidine + Compound
W256	0.1	—	—	45		
	0.05	—	—	20		
	0.01	—	—	22		
W256	0.1	—	—	27		
	0.01	—	—	17		
FJ	0.05	Protamine	0.05	0	0	23
			0.01	0	—	49
FJ	0.05	Protamine	0.05	8	4	0
			0.01	8	—	11
FJ	0.05	Rutin	0.05	16	0	23
K2	0.05	—	—	0		
K2	0.05	Na deoxycholate	0.04	31	38	38
K2	0.05	Na deoxycholate	0.02	0	0	0
K2	0.05	Lysozyme	0.1	0	35	0

* W256 = Walker 256 rat carcinoma; FJ = Flexner Jobling rat carcinoma; K2 = Krebs-2 mouse carcinoma

inhibition at the 0.05 per cent level. The concentration definitely inhibitory is therefore about 100 times greater than that which we had found necessary to affect yeast cells, and about 25 times greater than that which Yushok (3) had found necessary (0.004 per cent) to effect Krebs ascites tumor cells. The relative ineffectiveness of tyrocidine as an inhibitor of glycolysis in tumor slices, particularly in the Krebs-2 carcinoma, was surprising since this solid tumor was produced from the Krebs-2 ascites tumor and was grown in the same strain of mice as that used for the ascites tumor.

The difference in effectiveness toward the tumor slices and the free ascites cells seemed to indicate that tyrocidine was not reaching the tumor cells in the slices. Various means were tried, therefore, to make the tumor slices more sensitive to tyrocidine. Substances known to affect cell permeability, to act on components of the cell surface, or to potentiate the effect of tyrocidine on other systems were tested (Table IV) in combination with tyrocidine during the glycolytic measurement.

With none of the compounds tried, was the inhibitory effect of the tyrocidine increased significantly.

Treatment of the tumor slices or the animal in various ways prior to the manometric measurement of glycolysis was then tried. The treatment was in general designed to make the tissue more permeable to tyrocidine by digesting some of the protein, fat or polysaccharide. In these experiments (Table V), the hyaluronidase, trypsin or lipase which

TABLE V.—*Effect of Tyrocidine on Glycolysis of Tumor Slices after Various Preliminary Treatments of the Slices or the Animal.*

Type of Treatment	Details of Treatment	Tumor*	Percentage Inhibition of Glycolysis: Tyrocidine Alone (0.05%)	Treatment Alone	Tyrocidine (0.05%) + Treatment
Hyaluronidase**	Slices incubated aerobically 2 hr. at 37° C. in KRP*** containing 0.01% hyaluronidase	FJ	12	0	29
Hyaluronidase	Ditto with 0.1% hyaluronidase	W256	12	0	0
Hyaluronidase	Tumor-bearing rat injected with hyaluronidase (8000 TRU in 0.5 ml. water around tumor 2 hr. before removal of tumor)	W256	—	—	66
Trypsin**	Slices incubated aerobically 2 hr. at 37° C. in KRP containing trypsin (2 mg./ml.)	K2	—	—	38
Lipase**	Slices incubated aerobically 2 hr. at 37° C. in KRP containing lipase (2.5 mg./ml.)	K2	—	—	0
Fat-free diet**	Mouse on fat-free diet 4 days before removal of tumor	K2	—	—	0

* See Footnote to Table IV.

** Hyaluronidase = powder from bovine testes, 175–250 turbidity reducing units (TRU) per mg. (Worthington Biochemical Sales Co.); trypsin = pancreatic powder, 1:250 (Difco Laboratories); lipase = pancreatic powder (Nutritional Biochemicals Corp.); fat-free diet = "Fat-free Test Diet" (Nutritional Biochemicals Corp.).

*** KRP = Krebs-Ringer phosphate solution with calcium omitted.

was added to the medium for the preliminary treatment was not present in more than trace amount during the glycolytic measurement, since the slices were removed from the original medium and transferred to the tyrocidine-containing Krebs-Ringer bicarbonate solution for the glycolytic measurement. From the data in Table V, it is apparent that the inhibitory effect of tyrocidine was not significantly increased by any treatment with the possible exception of hyaluronidase *in vivo*. The effect of hyaluronidase, which is known to increase permeability and to enhance the effect of many drugs, was studied further *in vivo*, in experiments included in the following section.

EFFECT OF TYROCIDINE ON TUMOR GROWTH IN MICE

Solid Krebs-2 carcinoma was produced in female Swiss white mice by subcutaneous inoculation with 0.1 ml. of ascites tumor fluid with-

drawn from a mouse of the same strain bearing a 7-day old ascites tumor. Solid tumors could usually be detected at the site of inoculation in 5 days.

The effect of tyrocidine on the growth of these tumors is shown in Table VI. Tyrocidine was administered in the food to the first two

TABLE VI.—*Effect of Tyrocidine, Alone and in Combination with Hyaluronidase, on Growth of Krebs-2 Carcinoma in Mice.*

Group No.	Method of Treatment	Tyrocidine Dose, mg.	Hyaluronidase Dose*, TRU	Regularity of Dose	Number of Mice	Duration of Experiment, days	Percentage Variation in Tumor Weight Treated /Controls
1	0.4% Tyrocidine in food	12–15	—	Daily	5	13	+26
2	2.0% Tyrocidine in food	60–75	—	Daily	5	9	−7
3-a	Intratumor injection of tyrocidine	0.4	—	Every 2nd day starting 6 days after tumor inoculation	4	20	+1
3-b	Intratumor injection of tyrocidine plus hyaluronidase	0.4	836	Ditto	4	20	+5
3-c	Intratumor injection of hyaluronidase alone (Control)	—	836	Ditto	4	20	+70

* The hyaluronidase had a potency of 1070 turbidity reducing units (TRU) per mg. It was a gift from the Wyeth Institute of Applied Biochemistry. We are indebted to Dr. J. Seifter for this sample.

groups of mice. Purina Lab Chow pellets were powdered and the tyrocidine mixed throughly in the powdered Chow. Control groups of five mice received the powdered Chow without tyrocidine. At the end of the experimental period, tumors were removed from the treated and control groups of mice and weighed. The effect of the tyrocidine on tumor growth was then calculated as a percentage variation of the average tumor weight of the treated mice from that of the control mice. With 0.4 per cent tyrocidine in the food, tumor growth was even greater than without tyrocidine. With 2 per cent tyrocidine in the food, tumor growth was only slightly less than without tyrocidine. The differences do not appear to be significant. In any event, there was no distinct inhibitory effect of the tyrocidine on tumor growth.

Tyrocidine was injected directly into the tumors in groups 3-a and 3-b (Table VI). Group 3-b received hyaluronidase along with the tyrocidine. Neither group which received tyrocidine showed any inhibition of tumor growth, while a control group 3-c which received the hyaluronidase alone showed a definite increase in the size of the tumors.

Reilly *et al.* (4) had previously attempted to inhibit tumor growth by intraperitoneal administration of tyrocidine to mice bearing Sarcoma

180. No inhibition of tumor growth was observed. Our experiments, in which the tyrocidine was administered by two other routes to mice bearing the Krebs-2 carcinoma, therefore confirm their observation of the lack of inhibition of tumor growth by tyrocidine.

CONCLUSIONS

The foregoing experiments point out that a substance, such as tyrocidine, which is a very potent inhibitor of both yeast fermentation and ascites tumor cell glycolysis, is not necessarily an effective inhibitor of glycolysis of tumor cells within a slice of solid tumor. This lack of inhibition in tumor slices is due undoubtedly to the fact that the tyrocidine does not reach the tumor cells. The inability to reach the tumor cells may be due to simple impermeability of the connective tissue surrounding the tumor cells, or it may be due to binding of the tyrocidine by some tissue component before the tyrocidine can reach the tumor cells.

The modern trend in studies of tumor metabolism is to use the ascites tumor cell as test material because of the high reproducibility of results. However, in spite of difficulties encountered in working with the tumor slice, the studies reported here show the importance of the slice in seeking materials for inhibition of glycolysis in solid tumors *in vivo*. If the test substance does not inhibit glycolysis in the tumor slice, there is little likelihood that it can inhibit glycolysis in the solid tumor *in vivo*.

SUMMARY

Tyrocidine was found to inhibit anaerobic fermentation and respiration of yeast when present in concentrations of 0.001 per cent and higher. The inhibition was slightly greater in the presence of phosphate than in its absence. Yeast hexokinase activity was inhibited by tyrocidine but the concentration required was about twenty-five times greater than that necessary to inhibit fermentation or respiration.

Tyrocidine also inhibited the anaerobic glycolysis of tumor slices, but a considerably greater concentration was required than for the inhibition of yeast fermentation or of ascites tumor cell glycolysis. Attempts were made to increase its effectiveness toward tumor slices by various treatments of the slices or the tumor-bearing animal. Only hyaluronidase injection *in vivo* seemed to increase the inhibitory effect of the tyrocidine toward glycolysis of the tumor slices.

Tyrocidine fed to mice, or injected alone or with hyaluronidase, did not retard the growth of solid Krebs-2 carcinoma.

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ALGEBRAIC GEOMETRY AND TOPOLOGY, A SYMPOSIUM IN HONOR OF S. LEFSCHETZ, edited by R. H. Fox, D. C. Spencer and A. W. Tucker. 399 pages, 6 × 9 in. Princeton, Princeton University Press, 1957. Price, $7.50.

In 1954 a meeting was held to honor S. Lefschetz on his 70-th birthday. His students, colleagues, and friends from throughout the world gathered in Princeton to discuss and to present papers on their recent research in the branches of mathematics called *algebraic geometry* and *topology*. These papers have been gathered in a book, preceded by two articles by W. V. D. Hodge and by N. E. Steenrod on the work and influence of Lefschetz in these two fields, and by a bibliography of his published work.

The papers are grouped in two parts: twelve in algebraic geometry, and eleven in topology. Both groups reveal the extreme abstraction and generalization which have come to these fields in recent times, a phenomenon due in part to a natural tendency in this direction, but mainly to the conscious modern effort to view mathematical results in their natural settings. Thus, in addition to classical notions of algebraic geometry, one finds in the first group of papers abstract varieties, Kähler manifolds, complex structures, and almost-complex structures. The specific results presented are too numerous, various, and technical to catalog.

The two articles are developed in considerable technical detail. Lefschetz published his first paper in 1912. At that time topology (then called "analysis situs") was in its infancy, and it was by no means apparent then that this infancy would be survived; that the subject existed at all was due almost entirely to the work of B. Riemann and Henri Poincaré. Algebraic geometry was considerably older (being traceable all the way back to Descartes); it had been developed to considerable depth mainly (but not exclusively) in the theory of curves and of surfaces, by Riemann and his followers in Germany, by the prolific Italian school, and by the work of Poincaré and E. Picard in France. It is perhaps symbolic that 1912 was also the year in which Poincaré died, for Lefschetz became a worthy continuer of much of his work. In 1953, when Lefschetz retired from his professorship at Princeton University, topology and analytic geometry had grown into two of the most active, vigorous, and profoundly developed subjects in all of mathematics, and a considerable part of this growth was due, either directly or indirectly, to Lefschetz. He exercised his influence in three ways: by his own research; by the ideas which he introduced which were subsequently exploited by others; and by the students he trained and inspired, who in turn became mathematicians of high quality.

E. R. KOLCHIN
Columbia University

GALACTIC NEBULAE AND INTERSTELLAR MATTER, by Jean Dufay, translated by A. J. Pomerans. 352 pages, plates, 6 × 9 in. New York, Philosophical Library, 1957. Price, $15.00.

Galactic Nebulae are among the most fascinating and, at the same time, the most mysterious objects in the sky. Of various shapes, sizes, distances and content, they defy regimenting into intelligible patterns. Yet from these objects comes some of the basic knowledge of the size, content and structure of our Milky Way system.

Their study is of rather recent origin and within the past year this is the second definitive book to appear on this subject. It is only recently that the experimental and theoretical backgrounds necessary for an analytical treatment of these objects have been assembled. Today the prior research has brought into sharp focus those features which will shape the answers of the future.

In *Galactic Nebulae and Interstellar Matter*, Jean Dufay, director of the Lyons and Haute-Provence Observatories, has presented a superb resume of our knowledge of these objects.

He has divided the book into four sections, the first of which deals with atoms and molecules in space. It is in this section that the gaseous nebulae are treated. Forbidden lines, stars associated with planetary and diffuse nebulae, the three methods of line excitation, temperatures, emission in the

visible, ultra-violet and radio parts of the electromagnetic section and absorption are covered.

Part II deals with solid particles in space. One of the most challenging aspects of the entire subject is the determination of distances. The various methods and their correlations are delineated. A thorough discussion on absorption is given along with the nature and dimensions of the scattering particles.

"From atoms to grains and from grains to stars" is the subject of part III. The coalescing of atoms to grains is covered along with the role radiation pressure plays in bringing them together into globules. In this section the polarization of stellar light by interstellar matter is given along with the astronomical attempts at theoretical interpretation of the effect. From globules to stars concludes the section.

The last section involves diffuse matter outside the Milky Way. The scale of the universe is intimately tied to the presence of absorbing material between the galaxies and, if we are to determine the penetrating power of our instruments, it is essential that we resolve the problem of matter in intergalactic space.

Dr. Dufay has performed a magnificent service to astronomy in attempting a discussion in this field. While this is a pioneering approach of relatively few pages, its significance is of the highest order.

Dr. Dufay's book is destined to have tremendous impact on this facet of astronomy.

I. M. LEVITT
The Fels Planetarium

AN INTRODUCTION TO MATRIX TENSOR METHODS IN THEORETICAL AND APPLIED MECHANICS, by Sidney F. Borg. 202 pages, 9½ × 11 in. Ann Arbor, J. W. Edwards, Publisher, 1956. Price, $4.75.

The author states that "The book is primarily an engineering treatment of matrix and tensor methods in Structures, Fluids and Mechanics." He further points out two objectives of the book. One, to emphasize "the essential unity (and also points of difference) of the various fields of Applied Mechanics." The second, to fill a need for a textbook covering the application of tensor analysis that an engineering student can understand without a formal course in tensor analysis.

In carrying out these objectives the author introduces the mathematics (matrix algebra, vector analysis, complex variable theory and tensor analysis) in the first two chapters. This development is more in the way of a brief review of only the gross fundamentals of the topics mentioned. The discussion of tensors is confined to those of zero, first and second orders of relative weight zero in one, two and three space. A reader of the book will gain no general knowledge of tensor analysis but will see a number of problems in mechanics investigated using some of the simpler properties of matrix tensors.

An introductory chapter to the theory of elasticity precedes one which examines in a general way the bending problem and the torsion problem. Other chapters deal with the theory of plates and shells, viscous flow, boundary layer theory, the theory of plasticity, curvilinear coordinates and dimensional analysis.

It is felt that the book will serve the author's intended purpose though a teacher using the book as a text might easily supplement the discussion of the mathematical tools manyfold times. A prerequisite for taking such a course should be at least vector analysis.

WILLIAM MCKAY
The Franklin Institute Laboratories

DAIRY MICROBIOLOGY, by Edwin M. Foster, F. Eugene Nelson, Marvin L. Speck, Raymond N. Doetsch and Joseph C. Olson, Jr. 492 pages, diagrams, 6 × 9 in. Englewood Cliffs, N. J., Prentice-Hall, Inc., 1957. Price, $5.65.

Dairy Microbiology has appeared to fill an increasingly acute need in a field of study where no up-to-date textbook previously existed. Written by five of the country's leading dairy bacteriologists in as many different land grant universities and colleges, it represents a very good cross section of current knowledge and opinion in a rapidly moving field of applied science and technology. It is not intended by the authors that the book should be a self contained treatise on dairy microbiology but was designed for students and workers in the field who had

previously had college courses in general microbiology and chemistry.

The arrangement of the subject matter is such that it leads from the general to the specific. The early chapters deal with some of the biological characteristics of bacteria, leading into a classification of dairy microorganisms from the standpoint of both taxonomic considerations and physiological characteristics. There is a somewhat detailed discussion of factors affecting the growth and death of microorganisms. Following a chapter on "Microbiological Methods of Examining Dairy Products" the discussion leads directly into sanitation and the control of microorganisms in the unfermented products such as market milk, concentrated and dry milk products and frozen products. The microbiology of dairy starters, fermented milks and an excellent discussion of the microbiology of a wide variety of cheeses follow in that order. There is a chapter on the microbiology of cream and butter. Finally, there is included a very timely chapter on dairy plant waste disposal, including the recovery of some of the valuable whey constituents.

The progressive approach has its disadvantage, however, in that the theoretical discussions sometimes appear to be separated too far from the specific application. This separation can be bridged by reference to the excellent index, but it might have been easier for the reader to follow had page references to the theoretical discussions been included in the appropriate places in the later chapters.

With the widespread interest in the public health aspects of the dairy industry, the reader may feel frustrated from the lack of any organized section dealing with this problem. In the various chapters on specific products one will find short discussions of the particular products in relation to disease transmission, but the treatments are brief and somewhat superficial.

In spite of the effort to make the whole book the product of all of the authors, one can easily detect differences in writing style in different sections. These differences undoubtedly reflect the relative abilities of the different authors to communicate highly technical information to the less technically trained reader. In some areas, especially in the early chapters, the use of a simpler vocabulary, even at the risk of lengthening the discussion, would have broadened the applicability of the book to the less trained and less skilled plant employees and undergraduate dairy students.

In general, however, the book will make an excellent textbook and reference book. It is well documented throughout with references to the literature for the benefit of those who wish to study further. For those who are unfamiliar with the details of manufacture of dairy products, sufficient information of this sort is included to orient the student. There is a good selection of photographs and diagrams throughout the text. Grammatical and typographical errors have been kept to a minimum.

J. FRANK CONE
The Pennsylvania State University

NUCLEAR REACTOR PHYSICS, by Raymond L. Murray. 317 pages, diagrams, 6 × 9 in. New York, Prentice-Hall, Inc., 1957. Price, $10.00.

Nuclear Reactor Physics is a welcome book, because of its straightforward presentation of reactor design, together with its numerous practical examples.

This combination of the proper dosage of reactor theory and practical application is relatively rare. Ever since the first reactor engineering book containing declassified information was published in 1949, most of the books have either contained ample reactor theory with few practical illustrations, or little reactor theory, being more concerned with the engineering aspects.

The major emphasis throughout this text is on the distribution in energy and space of neutron flux, the determination of the critical amount of fissionable material, and the transient behavior and control of the reactor as a heat source.

The reactor theory is more advanced in this text than in Murray's first book, *Introduction to Nuclear Engineering*. But the chapters on shielding and fluid flow, contained in his first volume, are omitted here.

The first four chapters in *Nuclear Reactor Physics* serve as an excellent introduction to the novice in the reactor field. These chapters contain clear-cut explanations of reactor processes, neutron cross

sections, neutron diffusion equations and one-energy group calculations of the flux distributions in homogeneous and heterogeneous reactors. Also, these explanations might help the practicing reactor engineers to grasp more clearly the fundamentals of reactor design.

The subsequent chapters introduce the reader to the different techniques in the nuclear field; such as, two-energy group theory, transient responses, dynamic relationships in the nuclear power system, control-rod theory, transport theory, and multigroup methods.

One of the reasons why Murray's book is so valuable is that it compiles in one text the latest design methods, previously found in different periodicals and reactor handbooks. However, the cursory description of certain techniques may be insufficient for the practicing engineer. He could then refer to the helpful list of references at the end of each chapter.

The reader is also introduced to analogue and digital computer techniques essential for solving some nuclear problems. Analogue simulators are described for transient reactor kinetic equations and two-energy group flux calculations. Also, the difference approximation methods useful in determining the flux by digital computer calculations are shown.

Incidentally, the appendices on Bessel Functions and Laplace Transforms would be of assistance to the design engineer.

By reading this practical text, both a nuclear engineering student and a practicing nuclear engineer would understand more clearly the physical concepts and calculation methods in the expanding reactor field.

MUSA HALEV
The Franklin Institute Laboratories

THE DESIGN AND CONSTRUCTION OF ENGINEERING FOUNDATIONS, by F. D. C. Henry. 547 pages, diagrams, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $9.00.

The great advances made in the science of soil mechanics in the past two and a half decades have been of invaluable aid to the foundation engineer. Knowing what the subsoil conditions are from adequate test borings and with the knowledge of how such subsoil or rock behaves under the anticipated structural loads, the civil engineer can design the proper foundation with much more assurance than he could in years past. Mr. Henry, practicing civil engineer in Great Britain, recognizes the value of soil mechanics and geology in the successful design of engineering foundations. Gathering together the results of pertinent research in these fields, he has applied these results along with his years of practical experience to produce an impressive study of the design and construction of engineering foundations.

Not particularly well written—the text sometimes labors and the continuity could occasionally be improved—the book nevertheless contains a formidable amount of information on foundation engineering. Commencing with a review of geology pertinent to foundation construction, there follows a thorough treatment of the principles of soil mechanics and the design of reinforced concrete and its general application in foundation construction. Then the design of specific types of foundations to meet various kinds of subsurface conditions is discussed in considerable detail. This covers single and continuous footings, retaining walls and culverts, cofferdams and caissons, bearing piles, bridge abutments and piers, underpinning, and structures liable to the effects of mining subsidence. Believing that problems illustrating the design of various foundation structures are the best means of explaining design, the author has wisely included more than a hundred such problems with their solutions in the appendix.

E. W. HAMMER, JR.
The Budd Company

QUANTUM CHEMISTRY, AN INTRODUCTION, by Walter Kauzmann. 744 pages, diagrams, 6 × 9 in. New York, Academic Press Inc., 1957. Price, $12.00.

The usual experience of the chemist who studies quantum mechanics is somewhat similar to the following: a) He first becomes interested in the basic concepts of quantum mechanics, and enthusiastic as to the basic understanding it will give him of chemical phenomena; b) He then realizes that a very considerable mathematical knowledge is required to understand the subject. He must have not only a very good ground-

ing in what we might call "ordinary mathematics"—calculus and differential equations, but he must acquire also a knowledge of specialized mathematics, and mathematical concepts, such as Legendre functions, Laguerre polynomials, and the other specialized procedures necessary for the solution of wave equations. He will then give up the problem as hopeless (for him) and return to reading descriptive chemistry, or he will acquire the necessary mathematical fundamentals. c) If he acquires the mathematical knowledge necessary, he is now ready for the third, and even more frustrating stage: He will now study many chapters on the behavior of waves, on the mathematical behavior of the hydrogen atom, and then he will suddenly realize that having applied a semi-scientific procedure to the study of the hydrogen atom, he must stop there and take an entirely different course if he is to solve the practical problems of theoretical chemistry. He must approximate, he must build up structures which have no physical meaning, he must think in terms of mathematics instead of in terms of the physical world.

However, there is a brighter side to the picture: To quote Kauzmann, "In the ten years during which quantum mechanics was first applied to chemistry, many fundamental problems of long standing were solved. The covalent bond, the periodic system . . . , the aromatic character of benzene, the stereochemistry of carbon . . . , the mechanism of bimolecular reactions, the existence of free radicals, van der Waals forces, the magnetic properties of matter, the conduction of electricity by metals. . . ." However, "Accurate quantum mechanical computations on any but the most simple systems have turned out to be far beyond the capacities of the best computing systems."

The subject matter of Kauzmann's book is divided into five main sections. Part I gives the mathematical background necessary for the study of quantum mechanics, including Operators, Complex Numbers, Vectors, Probability Functions, Differential Equations and Determinants. The Classical Theory of Vibrations in one, two and three dimensions and the mathematics necessary for their understanding are given in detail. Part II covers the General Principles of Quantum Mechanics, and includes the Schroedinger equation and its solutions, the uncertainty relations and angular momentum. Part III, Atomic Systems, discusses hydrogen, helium, electron spin, and takes the reader into the more complicated field of orbital energies, multiplet structure, and the magnetic properties of atoms. Part IV, Molecular Systems, now takes up hydrogen and other diatomic molecules, and leads into the subjects which we think of as being *chemistry:* aromatic compounds, chemical bonds, and approximations of the wave equations as applied to chemistry. Part V covers Systems in Non-Stationary States, under which the author includes resonance and tautomerism, and two excellent chapters on the interaction of matter with light.

It is recognized by the author that the purposes of the various readers of this book will be different. Because of this, he makes a suggestion that seems to be worthy of adoption in many other cases: He recognizes that many readers "will not want to wait so long before getting their teeth into quantum mechanics," and will wish to cover the preliminaries only as they are necessary. For this reason the author suggests a study plan which covers: Essential mathematical background, concepts and laws of quantum mechanics, solutions of Schroedinger's equation, uncertainty relations, atomic structure, and molecules and the chemical bond. This study plan seems to the reviewer to be an excellent one, particularly for the scientist who has many other subjects for study than quantum mechanics.

To each chapter very complete references are appended, both specific and general. The book is well printed and bound, on good paper. The type face is excellent. *Quantum Chemistry* by Kauzmann can be recommended highly for the advanced chemical student, the working scientist, and the seeker after knowledge, wherever he may be found.

GEORGE S. GARDNER
American Chemical Paint Co.

PRINCIPLES OF ENGINEERING GEOLOGY AND GEOTECHNICS, by Dimitri P. Krynine and William R. Judd. 730 pages, illustrations, 6 × 9 in. New York, McGraw-Hill Book Co., Inc., 1957. Price, $10.00.

Another book in a recent trend showing the dependence of one science upon another, *Principles of Engineering Geology and Geo-*

technics ably shows the importance of an adequate knowledge of geology and associated earth sciences as the basis for a sound background in foundation engineering. For many years now Mr. Krynine, now an independent consulting engineer, taught soil mechanics at Yale University, and this book reflects his wide knowledge of the subject.

As the authors point out, geotechnics is the application of earth sciences to the solution of civil engineering problems. These pertinent earth sciences are petrology, geomorphology, pedology, geohydralogy, geophysics and seismology. Their significance in connecton with civil engineering is discussed in chapters on rocks and minerals and their engineering properties, soils and soil mechanics, subsurface water and subsurface exploration, and mapping. How this information is used in practice is then described in the remaining half of the book. Specific applications are in tunnel design, various foundations on underfrost and permafrost conditions, shore-line engineering and river improvement, sedimentation engineering, foundations for buildings, bridges, pavements and dams, and earthworks, landslides and earthquakes. The book is concluded with a very interesting chapter on the legal aspects of general contracting.

Generously referenced and well illustrated, *Principles of Engineering Geology and Geotechnics* is a notable addition to the series of Civil Engineering books that McGraw-Hill has been publishing in the last decade. Under one cover, it describes all the significant factors to be considered in the design of most types of engineering structures that require foundations of one sort or another.

E. W. HAMMER, JR.
The Budd Company

VENOMS, edited by Eleanor E. Buckley and Nandor Porges. 467 pages, illustrations, 6 × 9 in. Washington, American Association for the Advancement of Science, 1956. Price, $9.75.

This is a symposium volume of papers contributed to the First International Conference on Venoms at the December 1954 meeting of the AAAS in Berkeley, Calif. It has been edited by Eleanor Buckley of Wyeth Laboratories and Nandor Porges of the U. S. Department of Agriculture, and has been issued as Publication No. 44 of the AAAS.

"People have been scourged from antiquity by the bites and stings of insects, fish, mammals and snakes. With the natural fear of being attacked by some hostile, living thing, there has also been associated the actual experience of pain, distress, and often death, resulting from the bite. For thousands of years there has been interest and fear about animal bites and their effects." And for thousands of years treatment of animal envenomation has been totally empirical, sometimes effective, and quite irrational. This conference was called to collate what is known about the chemical nature of these toxins, to present methods of treatment, and to stimulate further research.

The mortality from snakebite in the world has been estimated by the World Health Organization as 30,000 to 40,000 per year, the large majority of deaths occurring in southern and southeastern Asia, followed by South America. The pit vipers of the United States (rattlers, copperheads and moccasins) and coral snakes take an annual toll of only 10 to 20 lives.

"Most of the toxic factors in snake venom have been attributed . . . to proteolytic enzymes, phosphatidases and neurotoxins. The proteolytic factors cause hemorrhagic and coagulant effects. . . . Hemolysis by the phosphatidases is increased by the formation of lysolecithin. . . . The neurotoxins attack the nervous system and produce paralytic and curare-like reactions."

Although the most publicized and most common source of venoms poisonous to man, snakes are not the only culprits. In some areas scorpions, spiders, jellyfish, corals, stingrays, sharks, and other poisonous fish take their toll of lives by biting, stinging, or mere contact. Protozoans may cause death by paralytic shellfish poisoning, when infected animals are eaten, and there are many species of fish poisonous on ingestion, as well as king or horseshoe crabs, some turtles, and seal and bear liver.

The relatively lesser annoyances of insect stings, and the various unpleasant effects of touching catfish, sea urchins and sea cucumbers, starfish and marine sponges, are more widespread.

For many of these toxins, there is no known antidote. However, antivenins for treatment of envenomation by many species of snakes, scorpions and spiders have been prepared by hyperimmunizing horses. A list of those available is presented. Among the many methods of treatment tried and discussed, the neutralization of the toxin by the specific antivenin is the most beneficial. Infection may contribute largely to death from snakebite, therefore antiseptic measures are also necessary.

This fascinating and well organized book presents several challenges. (1) There are many gaps in knowledge concerning animal venoms, such as chemical constituents, their mode of action and physiological effects. When these are filled, a rationale for treatment exists. (2) The impression is that some existing snake antivenins could be improved, and as yet some have not been successfully manufactured. (3) ". . . many of our most valuable drugs are poisons. However, safe and practical medical use is dependent on a thorough knowledge of their chemical structures, toxicities, tolerances, physiological activities, and limitations."

The field of venoms, "one of the most complex dilemmas devised by nature," offers many research problems in many fields of science.

BARRY AND NORMA ROTHMAN
Philadelphia Herpetological Society

INTRODUCTION TO OPERATIONS RESEARCH, by C. West Churchman, Russell L. Ackoff and E. Leonard Arnoff. 645 pages, diagrams, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $12.00.

It is rather difficult to assess this book since its purpose is somewhat diffusely stated. It is neither a text nor a comprehensive reference for the field. Perhaps the best characterization is as a guide to the problem solving techniques of operations research written for the reader of moderate mathematical training. Considerable effort is spent in detailed discussion, together with examples, of classical operations research models, such as queuing theory, and this is all to the good.

There are, however, several lamentable omissions in the text. One would expect that a subject as intimately concerned with stochastic processes as operations research, would naturally demand an emphasis on matters such as time series analysis, sampling, etc. Although sampling is discussed on a verbal level, there is no immediately applicable material presented. The chapter on the analysis of the organization is again a verbal rather than a particularly useful piece of work. This is to say, a bow is made in the direction of servomechanism theory, but no adequate discussion of the content of the field is presented. One could raise questions about servos with random input, adaptive servos, optimalizing servos, all of which are more pertinent to organization theory than nebulous efforts to draw formal parallels between diagrams of a nervous system and diagrams of electrical networks.

The description of the human operator in systems as either a controller or decision maker is treated negligently at best. It is hard to see how a study of man-machine systems can ignore one of the important and ubiquitous components.

In addition to the omissions, there are several remarks which might better have been omitted. For example: Page 519, "In this early work von Neumann was not so much interested in executive type problems as he was in the logical foundations of quantum mechanics." (The paper cited here makes it perfectly clear that von Neumann understood the potential applications to economics and business; furthermore, his work on game theory was independent of his other research.) Also on the same page, "It was not until 1944 . . . that the mathematical treatment of games took fire." (Actually 1948, with the advent of government support for projects at Rand and Princeton, is a more reasonable date. Kaplansky was the only mathematician to publish in the theory prior to 1948, save for the von Neumann and Morgenstern work.)

On pages 349, 350 and 367, reference is made to Flood's technique on the Hungarian Method as developed by Flood. In reference 7, p. 367, of the text, Flood gives proper credit to the technique by referring to a paper by Kuhn, who developed the Hungarian Method. It is unfortunate that the authors were not equally careful.

EZRA S. KRENDEL
The Franklin Institute Laboratories

BOOK NOTES

OPTICS, THE SCIENCE OF VISION, by Vasco Ronchi, translated by Edward Rosen. 360 pages, diagrams, 6 × 9 in. New York, New York University Press, 1957. Price, $10.00.

Published originally in Italian, in 1955, *Optics, the Science of Vision* has been translated by Edward Rosen, so that Ronchi's important treatment of optics may be more readily accessible to English language scientists. Ronchi discovered that the rules of classical optics were demonstrably false because they operate only under perfect conditions without taking into account the limitations of the observer. This volume is the result of 40 years of study to integrate optics with physics, physiology and psychology. The author challenges the mathematical concepts of classical optics—and the results should prove to be stimulating reading for all scientists, engineers and medical men interested in the problem of vision.

PHOTOGRAPHIC SENSITIVITY. VOL. 1, edited by Shin Fujisawa. 147 pages, diagrams, 7 × 10 in. Tokyo, Maruzen Co., Ltd., 1956. Price, $4.00.

In September 1953, a Symposium on Photographic Sensitivity was held at Lake Hakone in Japan. The proceedings of that symposium have been published in English and are available from the Maruzen Co., Ltd., in Japan.

The book is divided into two sections. Section A on Physical Properties contains ten papers and an introductory survey, one of which was presented by Frederick Seitz and the rest by Japanese authors. Section B on Photographic Emulsions comprises nine research papers, an introductory survey and a summary of Japanese research work on photographic sensitivity. Nevill F. Mott is the only non-Japanese author in Section B. Further symposia are planned.

ORGANIC CHEMISTRY, by H. Harry Szmant. 803 pages, diagrams, 6 × 9 in. New York, Prentice-Hall, Inc., 1957. Price, $7.95.

A new approach to the subject of organic chemistry is found in this beginner's text. The author, believing that it is not necessary to understand the entire history of the subject (including obsolete processes, etc.) in order to appreciate the latest developments, has omitted a lot of material usually included in beginning texts. Emphasis is on theoretical and industrial aspects. Three parts of the book (General Theory, The Chemistry of the Important Families of Organic Compounds, and Miscellaneous Topics) are each subdivided into chapters covering one phase of the subject.

COLLEGE PHYSICS, by Robert T. Beyer and A. O. Williams, Jr. 660 pages, diagrams, 6 × 9 in. New York, Prentice-Hall, Inc., 1957. Price, $7.50.

Although intended for a full year's course in general physics, this text can also be used for a one-semester course by omitting certain chapters named in the preface. Since the text is primarily for liberal arts students, the main principles of physics are studied, and the secondary topics are omitted. In line with the liberal arts approach, the history of physics is dealt with, as well as its place in modern civilization. The student needs as a prerequisite mathematics through elementary trigonometry only. Three appendices summarize briefly the necessary mathematics, including tables of natural and common logarithms.

A SECOND (M.K.S.) COURSE OF ELECTRICITY, by A. E. E. McKenzie. 317 pages, illustrations, 5½ × 8½ in. New York, Cambridge University Press, 1957. Price, $3.50.

This is a simplified version of the author's *Second Course of Electricity*, modified to use the rationalized m.k.s. system of units. It is intended not only as a text, but also as an attempt to convince skeptics of the value of the m.k.s. system. Sixteen chapters cover the complete range of work in electricity, from the early work to atomic physics.

V.H.F. TELEVISION TUNERS, by D. H. Fisher. 136 pages, illustrations, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $6.00.

The tuner has only recently been added to the TV receiver in England. This British volume on the subject of the TV tuner, then, is directed at those who must test and service the tuner. Of the three sections comprising the book, the first one (Tuner Design) deals with the broad problems involved, such as performance criteria, signal-frequency multiplication, oscillators, etc.). Section II (Tuner Construction) describes switch tuners and turret tuners; Section III (Tests, Measurements and Servicing) covers the practical aspects of servicing and testing the TV tuner.

FREQUENCY MODULATION RECEIVERS, by J. D. Jones. 114 pages, diagrams, 5½ × 8½ in. New York, Philosophical Library, 1957. Price, $6.00.

The seven chapters in this British book cover the principles and operations of frequency modulation receivers. After an introductory chapter describing both AM and FM, the author discusses the reception of frequency modulation and compares it with AM. Explained in detail, in later chapters, are the R.F. stage, the frequency changer, the I.F. stage, the FM detector, and the complete receiver (a circuit diagram).

PUBLICATIONS RECEIVED

The Editors wish to call attention to these new books, received in the JOURNAL office for review. Lack of space prevents publication of more than this listing.

A KEY TO THE STARS, by R. van der R. Woolley. Third edition, 141 pages, plates, 5 × 7¼ in New York, Philosophical Library, 1957. Price, $4.75.

CALCULUS WITH ANALYTIC GEOMETRY, by Richard E. Johnson and Fred L. Kiokemeister. 650 pages, diagrams, 6 × 9 in. New York, Allyn and Bacon, Inc., 1957. Price, $7.95.

MANUFACTURING PROCESSES, by Myron L. Begeman. Fourth edition, 612 pages, illustrations, 6 × 9 in. New York, John Wiley & Sons, Inc., 1957. Price, $8.00.

SEMICONDUCTOR ABSTRACTS, edited by E. Paskell. Volume III—1955 issue, 322 pages, 8½ × 11 in. New York, John Wiley & Sons, Inc.; London, Chapman & Hall, Ltd.; 1957. Price, $10.00.

COMPUTING WITH DESK CALCULATORS, by Walter W. Varner. 108 pages, 7 × 10 in. New York, Rinehart & Company, Inc., 1957. Price, $2.00 (paper).

CURRENT TOPICS

Electronic Brain the Size of TV Set.—A high-speed digital computer, not much larger than a home television set and requiring less power to operate, has been developed at Bell Telephone Laboratories.

This newest addition to the family of electronic "brains" was developed under Air Force contract. It has been named "Leprechaun," after the tricky sprite of Irish folklore.

Compared with previous computers, Leprechaun operates with a drastically reduced number of components. Excluding its magnetic cores, it uses only about 9,000 electrical components. More than half of these are transistors, the tiny electronic devices invented at Bell Laboratories. Some 5,000 of them are used in Leprechaun. The use of transistors made possible the small size and low power requirements of the computer.

Leprechaun represents a significant advance in computer design. One of its outstanding features is its flexibility. Its components can be easily connected and disconnected. This allows the computer to be used as a test model for research on digital computers designed for military applications. Proposed new designs can be laboratory tested through the use of Leprechaun without resorting to construction of new equipment.

Another feature of the new computer is its transistor-driven "random-access magnetic core memory." The machine can take its instructions immediately from its memory, no matter where the desired instruction may be stored. This process differs from that of computers with a "revolving drum memory" which may require time for the rotation of the drum before the instruction can be taken from its place.

Almost instantaneous solutions to the problems it has to solve are provided by Leprechaun since any of its stored instructions are immediately available. Each instruction consists of the operation to be performed, such as addition, multiplication, etc., and the location of the data in the memory.

The machine can store 1,024 "words" in its memory. These words consist of 18 binary or dual digits, representing instructions or data to be used in solving problems. In computers, all information is translated into a special code which uses only combinations of 0 and 1. These binary digits can be represented in Leprechaun by the flow or absence of electricity in the transistors, by the direction of magnetization in the memory cores or by holes in punched paper tape.

One reason for building Leprechaun was to demonstrate the feasibility of "direct coupled transistor logic." This is a switching circuit technique in which transistors are used to perform logic or "brain" operations as well as to provide power.

Compared with previous computers, the circuits of Leprechaun are very simple and easily understood. This is an advantage in engineering and maintenance since less experienced personnel are required to keep it in operating condition. Leprechaun's simplicity and small number of components result in small size and weight and will permit the use of automation techniques in manufacturing. All

these features insure greater reliability, which is of primary importance in military operations.

While Leprechaun is still in the experimental stage, the techniques developed are expected to have many future applications.

Additional Technical Information on Leprechaun

Leprechaun is to be used for programming and logical design research on digital computers for military real-time control applications.

Major factor in the reduction in size and power consumption of this computer is the introduction of direct-coupled transistor logic (DCTL) circuitry. A major objective in the development of this computer was to demonstrate the feasibility of the DCTL system.

Since Leprechaun can be used for research in computer design for military applications it was designed to have extreme flexibility. Mechanical and electrical arrangements are such that the various components can be easily connected, disconnected and interconnected to test proposed new designs. Interconnections consist of jumpers with taper pin terminals, thus making it possible to set up an entirely new circuit in a relatively short space of time.

Word length, determined by the control application, is 17 binary digits including sign. Except for this limitation, Leprechaun is a general-purpose computer, and may be described as a single-address, stored program machine with a 1024-word random access magnetic core memory.

In logical organization, Leprechaun is parallel, asynchronous, and all shifting registers and counters use the double rank technique. In general, the major units of the computer operate almost independently, at their own speed, doing as much as they can until forced to stop and wait for the services of some other unit which is busy.

The operation code for Leprechaun provides all the common arithmetic, logical, and transfer operations. A special feature is an unconditional jump operation (subroutine jump) to simplify the inclusion of short subroutines in a program. The first use of the operation transfers control to the desired loop in the program; the second use returns control to the point in the main program from which the jump was made.

A simplified address modification operation has been designed into Leprechaun in which modification is accomplished by direct substitution. The contents of a 5-bit Address Modifier Register are substituted for the five least significant address digits of all instructions in which these five digits are zero. This does not alter the stored instruction and requires no tags on the instructions to be modified.

Storage is provided by an 18,000-bit coincident-current transistor-driven magnetic core memory, organized to store 1024 18-digit words including a parity check bit that serves as a check on memory operation only. Access is provided by coincident voltage magnetic core diode switches. Using a system of staggered read drive, a 20-microsecond read-write cycle has been achieved.

Solid-state circuitry is employed in the power supplies. Basically, the circuitry consists of fast magnetic regulators using transistorized drivers, giving very effective regulation. For example, the 8 ± 2 volt supply for the memory has a static regulation of ± 1 per cent for an output current range of 0 to 1.8 amp., and its dynamic regula-

tion is less than ± 3 per cent under a pulsing load of 1.6 amperes.

Selected germanium alloy junction transistors with a 7 mc alpha cutoff make up the majority of the DCTL circuitry. A few surface barrier units are employed where accurate timing is important. Power transistors are used to develop the high current drives required in the memory.

Total power dissipation in the computer is about 160 watts, divided as follows: 20 watts in the DCTL portion, 48 watts in the memory, 82 watts in the power supply, and 10 watts in the indicator lamp circuits. Of the 20 watts dissipated in the DCTL circuitry, less than 2.5 watts are dissipated in the transistors.

Automation in the Post Office.—The use of electronic sorting machines in the British Post Office will mean the beginning of the end for hand-sorting of letters. Field trials of the machine have already been started, and altogether 20 machines have been ordered.

The British Post Office developed the letter-sorter in its own research laboratories. The machine handles letters of various mixed sizes. The control mechanism is partly mechanical and partly electronic. An operator sits at one end of the machine facing a window in which each letter is shown to him in turn. He has before him a key board with twenty-four keys—twelve for each hand. In addition, there are two special keys, one for cancelling wrong keying and the other for sorting letters to an unclassified selection. To sort a letter, the operator presses one of the twenty-four keys with each hand simultaneously, according to a combination which he has previously memorized. The letter then disappears from his view and is conveyed on the roller tracks by an electronically controlled memory device along rows of boxes until it reaches its proper box.

Another machine—a letter and package segregator—will be introduced when current trials are completed. It works as follows: the mails are tipped into a loading hopper and carried by a conveyor band to what is known as the "segregator drum." During their passage through this drum, thin letters slip through the hinged flaps which make up the outside of the drum, on to a conveyor below. Bulky things such as newspapers, packets and voluminous letters cannot pass through the flaps, and they emerge at the other end ready for hand stamping.

The thin letters are in turn taken by the conveyor running below the drum to two tower-shaped units which contain a series of spring rollers separated by some gaps. Short letters slip out through these gaps on to a collection device, but long letters bridge the gaps and are carried to the top of the towers. The separated streams of short and long letters are then carried on to their respective points to be faced the right way up and stamped.

Experiments are also being made with an electrically driven machine for counting postal orders. At present, approximately 600 million postal orders are issued annually from two depots in London and Edinburgh. The machine now on trial can handle up to 300,000 postal orders a day. It occupies little more space than a typewriter.

***U.S.S. Skate* Powered by Nuclear Reactor Plant.**—The world's first fleet-type nuclear submarine, the *U.S.S. Skate*, which was launched in May, is powered by the third full-scale operating nuclear reactor de-

signed and developed for the U. S. Navy by Westinghouse Electric Corporation.

"The *Skate* is the first of four fleet-type submarines with nuclear power plants to join the Navy's new 'atomic fleet,'" John W. Simpson, manager of the Atomic Energy Commission's Bettis atomic power plant in Pittsburgh, said.

The *Skate* reactor—a pressurized water type—is similar in principle to that of the *Nautilus* but incorporates new concepts and advances in reactor design based on improved nuclear technology. These advancements, have enabled engineers to develop a new reactor plant utilizing components of improved design which will operate more efficiently, permitting construction of a smaller craft to satisfy special service requirements.

In referring to the *Nautilus*, the Westinghouse executive recalled that Westinghouse began construction on the nuclear power plant for the *Skate* during the same month the *Nautilus* went to sea for the first time under atomic power—January, 1955. Developmental work had been underway several months prior to this time. The keel plate for the *Skate* was laid July 21, 1955.

New Carton Clamp.—The Yale & Towne Manufacturing Company of Philadelphia has announced the development of a carton clamp featured by a new narrow arm design which permits closer stacking of cartons and resultant better utilization of valuable storage space.

The clamp is unique in that its articulation is accomplished through the deflected metal construction of the arm. This design eliminates the need for bulky articulation arrangements on the outside of the clamp arm that require considerable waste space between stacks of cartons.

In order to achieve maximum pay load capacity with the new clamp, the clamp pads, two on each arm, are made of aluminum. The actual clamping surface is rough top rubber bonded to a thin metal sheet which is attached to the aluminum pad. This design provides excellent pressure distribution on the load.

The clamp can be built with pad reach up to 54 in. In the case of this maximum outreach model, each pad would measure 26 in. Standard pad height is 48 in.

The range of the clamp is 22 to 68 in. A typical load capacity is 2400 lb. at 21-in. load center on a 4000-lb. capacity truck.

The clamp will normally be arranged with three pressure settings for handling various types of carton loads. Yale's design, however, permits arranging the hydraulic system for a higher number of settings.

Another Yale design feature is the smooth, telescoping load back which provides a flat surface against which the load rides.

Electronic Control System Aids Ground-to-Air Defense.—An electronic control system capable of performing 136,000 mathematical steps in less than a second in assisting anti-aircraft operations center officers to organize a defense against approaching enemy aircraft, was unveiled for the first time in May.

The equipment, known as "Matabe," short for its official military title of Multi-weapon Automatic Target and Battery Evaluator, was demonstrated for a select group of high ranking U. S. Army and Air Force officers and

some of the nation's leading engineers and scientists, by the U. S. Army Signal Engineering Laboratory and the Burroughs Corporation at the latter's Research Center, Paoli, Pa.

The demonstration was conducted under security control, and only military men and others concerned with the specific uses of the equipment were permitted to attend. The visitors came from all parts of the country to witness the uncanny ability of the new addition to America's anti-airborne defense system.

Military leaders and engineers expect the machine to play a vital role in this country's ground-to-air defense.

"Matabe" is an outgrowth of an idea conceived by the U. S. Army Signal Engineering Laboratory, Fort Monmouth, N. J., to aid anti-aircraft officers to calculate in milliseconds the information needed to make the most favorable use of anti-aircraft weapons in the destruction of approaching enemy aircraft.

The machine is 29 ft. long, over 7 ft. high, consists of seven cabinets housing more than 20 miles of intricate wiring and thousands of electronic tubes, relays, resistors and other components. It has two control panels and is equipped with a 9-ton air-conditioning unit.

Dr. Irven Travis, vice president in charge of research and engineering for the world-wide Burroughs Corporation and head of the Paoli Center, pointed out that the heart of the system is a high-speed "real time" electronic digital computer that solves mathematical equations almost instantaneously.

"A machine operating at 'real time' speed provides information the instant it is needed, a vitally important factor in anti-aircraft operation," he said.

Daniel E. Eisenberg, Burroughs project engineer, told the group that "Matabe" calculates such information as:

Time it will take a missile to get from the battery to its burst point; how much time a battery needs to carry out its assignment (firing on attacking planes); at which point a missile will intercept a target; whether a target is within effective range of a battery; the "kill probability" of a battery-target assignment; the percentage of total bomb damage attacking planes are capable of inflicting; and the military worth of a target according to strategic goals, or in other words which plane or group of planes should first be singled out for destruction.

The machine, according to the engineer, keeps a running account of the history of fire on each target, and as assignments are made the survival probability of attacking aircraft is reduced by an amount equal to the predicted kill.

As the machine is informed by the operations center controllers of a kill, it automatically drops that target from the system before making its next assignment, it was explained.

It also records on punched paper tape the results of any type of raid for reference in mapping defense against future attacks.

To illustrate further the machine's tremendous speed, Eisenberg said it is capable of performing in one second 200,000 additions using 7 digit numbers.

It can handle 720 multiplications, 714 additions and 5 divisions in less time than it takes the fastest mechanical adding machine or desk calculator to do one simple addition problem, the engineer said.

Computations for assignment to anti-aircraft batteries are based on data derived from routine observations

and strategic compromises determined by experienced military officers and fed into the machine.

The comprehensive, yet flexible approach of "Matabe" to anti-airborne problems has made possible its expansion to a tactical analyzer, Eisenberg told the group.

It is capable of analyzing both air attack and defense plans. Its evaluations can lead to major tactical changes in specific attack or defense plans, in minor alterations in the position or type of batteries in a defense system, and aircraft in an attack pattern, he said.

Milton Epstein, project engineer for USASEL, said that "'Matabe' will give the Army that most important payoff in defense—TIME."

"There is no substitute for experience. And experience has shown the need for automatic, computational aids to the tactical personnel in anti-aircraft defense, particularly with a more potent and flexible enemy threat, and the consequent more intensive defensive measures and tactics necessary to cope with that threat," Epstein said.

Stethoscope Shuts off Unwanted Sound.—Three British medical men have collaborated in designing a new type of stethoscope which both amplifies sounds and allows the doctor to shut out *unwanted* sounds. It is said to be the first instrument of its kind. It is based on the principle that all sounds have a certain frequency, and it is so designed that a doctor can manipulate two controls so that only sounds of a particular frequency are carried to the ear pieces. With this stethoscope, a doctor can, for example, listen to the heart of a poliomyelitis patient in an iron lung while the latter is operating.

The brain of the instrument is contained in a compact box weighing only 18 oz. which is suspended from the neck. Two sets of ear pieces can be used simultaneously, and a tape recorder and a loud-speaker can also be connected. This last feature has an obvious value for teaching purposes. The microphone used with the stethoscope is also specially designed. It conveys only the sounds from the source with which it is in contact and is insensitive to all outside noises.

This instrument is now in full production by Airsonic Ltd., London, England. Numerous orders have already been received, including some from the United States.

New Precision Delay Generator.—The development of a new precision Delay Generator, the Type 6010, designed for laboratory type applications where accurate, variable, time interval pulses are required has been announced by the Electronic Instruments Division of the Burroughs Corporation, Philadelphia, Pa.

The Delay Generator consists of three modular constructed units with both power and signals internally interconnected by cabling to make a completely self-contained piece of test equipment. The three units comprising the complete generator and their functions are as follows:

Trigger Generator Type 101—provides a standard negative pulse output from an input signal composed of slow rising sine waves or fast rise time pulses of either polarity up to 100 kc. The unit can also function as a self-contained pulse generator, producing its own repetition frequency at any one of ten preset frequencies ranging from 50 cps. to 100 kc. A pushbutton switch, producing a single pulse each

time it is depressed, has been incorporated on the front panel for manual operation of the pulse generator.

Delay Generator Type 131—triggered by the standard negative pulse output from the Type 101 Trigger Generator, the unit produces five, precise, stable outputs; both positive and negative delayed pulses, positive and negative gating pulses, and a linear negative going ramp function. The time interval between output pulses is accurately controlled by a direct reading calibrated delay dial operating in conjunction with a five position switch ranging from 1 to 10,000 microseconds. In addition, provisions have been included for a Mixer Input and Output and an External d-c. Input. The Mixer stage can be used for mixing an external signal with the delayed pulse output. The External d-c. Input can be utilized for Analog to Digital conversion or a similar application.

Power Supply Type 9804—an electronically regulated supply with exceedingly low ripple characteristics, maintaining less than one millivolt rms of ripple on the output voltages. The unit provides three positive voltages and one negative voltage with regulation better than 0.5 per cent. A 30-second time delay circuit is included to automatically delay application of d-c. voltages to the other units until their filaments are sufficiently heated. The a-c. input line and the d-c. output lines are individually fused for overload protection and a small fan provides air circulation for heat dissipation.

Silicon Power Transistor Developed.—An experimental silicon power transistor, capable of providing an output of 5 watts at 10 megacycles either as an oscillator or an amplifier, has been developed at Bell Telephone Laboratories under the sponsorship of the Joint Services. Unilateral gain is in excess of 20 db., and a collector efficiency of better than 40 per cent has been achieved.

Details of this development were revealed in a talk prepared by Messrs. J. E. Iwersen, J. T. Nelson and F. Keywell of Bell Laboratories for presentation at the National Conference of Aeronautical Electronics in Dayton, Ohio.

The unit is a *p–n–i–p* diffused emitter and base transistor, in which a near-intrinsic or "neutral" layer of silicon separates the collector from the other elements. Introduction of an intrinsic layer to improve the high-frequency performance of transistors was announced by Bell Laboratories in 1954.

Alpha cutoff is about 100 megacycles per second, and some laboratory samples have provided as much as one watt output as an oscillator at 100 megacycles per second. Input and output impedances are on the order of 20 ohms and 300 ohms, respectively.

Original design objectives have been met in the laboratory models and development work on this unit is continuing. Steady improvements in the diffusion process, packaging, and other features are expected to result in a transistor which is highly reliable and relatively easy to manufacture.